MEDICAL DEPARTMENT

FIELD RESEARCH LABORATORY

Fort Knox, Kentucky

Med. Dep.
Annual Rep. Field Res. Laborat., Fort Knox

ANNUAL HISTORICAL REPORT

1947

MEDICAL DEPARTMENT FIELD RESEARCH LABORATORY
Fort Knox, Kentucky

MEDEA

SUBJECT: Annual Historical Report, 1947

TO: The Surgeon General
U. S. Army
Washington 25, D. C.

1. The following Annual Historical Report for the calendar year 1947 is submitted for your information.

2. Introduction (Historical Background)

The Armored Medical Research Laboratory was established at Fort Knox, Kentucky, on 1 September 1942.

The Laboratory was operated under the supervision and control of the Commanding General, Army Ground Forces, from 1 September 1942 until 3 February 1944, at which time control and supervision was transferred to the Office of The Surgeon General and the laboratory designated as a Class IV installation.

Effective 1 April 1947, the Armored Medical Research Laboratory was redesignated as The Medical Department Field Research Laboratory by War Department General Order No. 32, dated 19 March 1947.

3. Function

Under the general supervision of the Army Medical Research and Development Board of the Office of The Surgeon General, U. S. Army, to conduct research on various physiological and closely related aspects dealing with the inter-relationship between man and his equipment and supplies, disease, his environment and the military tasks assigned to him with the objective of constant improvement.

4. Organization

The Medical Department Field Research Laboratory is now composed of six sections comprising Administration, Psychology, Physiology, Biochemistry, Biophysics, Engineering and Testing.

Authorized strength is as follows:

Military	Authorized	Assigned
Officers -	24	19
Enlisted -	21	14
Civilians -	54	47
TOTAL	99	80

Grades and Ratings

Enlisted	Authorized	Assigned
Grade 1 -	3	3
Grade 2 -	2	3
Grade 3 -	6	2
Grade 4 -	6	6
Gradd 5 -	2	0
Grade 6 -	2	0
Grade 7 -	0	0
TOTAL	21	14

Source of Personnel

Military:

Officer personnel was for the most part composed of ASTP medical officers with special training and experience in medical research fields. These officers were obtained by screening the student classes at the Medical Field Training Center, Brooke Army Medical Center.

This method has been most satisfactory because of the number of young men with excellent scientific backgrounds who have obtained their M.D. degree under the Army Specialized Training Program. It was not at all unusual to find medical officers in this group who also had their Ph.D. degree in Physiology.

Enlisted personnel were for the most part obtained by requisition. The caliber of enlisted laboratory technicians has fallen rapidly with the acceleration of the discharge program in the early part of the year.

Civilian scientific personnel were carefully selected from civilian teaching and research institutions with the view of obtaining a well balanced staff of investigators of known reputation and wide experience in medical research fields.

Civilian personnel in the sub-professional, clerical and custodial grades were obtained through local employment agencies.

5. Physical Plant

The physical plant consists of the following buildings:

- 1 Permanent Building (Main Laboratory)
- 12 Frame Buildings (Cantonment Type)
  - 6 Two-story Barracks (1 Quarters, 3 Lab. Bldgs., 2 Supply Bldgs.)
  - 3 Mess Hall (1 Animal House, 1 Isotope Lab., 1 Storage)
  - 1 Recreation Hall (Conference Room)
  - 1 Company Supply (Machine Shop)
  - 1 Utility Building (Carpenter Shop)
- 1 Motor Pool (Garage and Maintenance)

The permanent laboratory building is of concrete block construction and is in an excellent state of repair.

Inadequacy of laboratory and storage space has necessitated the utilization of nearby frame structures which are usable but in poor state of repair. These buildings will be renovated and converted into temporary laboratories.

6. Accomplishments

Considerable progress was made during the year in restaffing the laboratory with qualified civilian scientific personnel.

Three qualified Reserve Officers were integrated into the Regular Army Medical Department. There was a gradual increase in number of personnel authorized and assigned during the year.

During the year, twelve projects were completed and reports submitted. (See Appendix A.) (See Appendix B.)

Six articles were published in scientific journals during the year. (See Appendix C.)

A test detachment was established in the Arctic for the purpose of collecting data on the effects of extreme cold on the military man in the performance of his military task.

Twenty-four projects are current at the end of the year. (See Appendix D.)

F. J. Knoblauch

F. J. KNOBLAUCH
Lt. Colonel, MC
Commanding

COMPLETED PROJECTS

PROJECTS COMPLETED IN 1947

1. Silica Content of Dust from Tank Ranges. Lt. Kruse, et al.

2. Efficiency of Signal Corps Operators in Extreme Cold. Blair, Gottschalk, Molnar.

3. A Critique of Physical Fitness Tests. Park, Bean, et al.

4. An Apparatus and Method for the Continuous Measurement of Evaporative Water Loss from Human Subjects. Palmes.

5. An Improved Mounting for Thermocouples for the Measurement of Surface Temperature of the Body. Palmes and Park.

6. A Method of Human Calorimetry. Palmes and Park.

7. Thermal Regulation During Early Acclimatization to Work in a Hot, Dry Environment. Park and Palmes.

8. Preliminary Observations on Physiological Nutritional and Psychological Problems in Extreme Cold, Ft. Churchill, Canada. Blair, J. R., et al.

9. Application of the Infra-red Gas Analyser to the Study of Human Energy Metabolism. Spoor.

10. Observations on the Relation of Height of Heel and Support in Arch of Shoes to Foot Physiology in Marching Troops. Magee, Davis, Milstead.

11. Test of Plastic Ear Molds for Communication Equipment. St. John.

12. Effect of the Cold Pressor Test on Glomerular Filtration and Effective Renal Plasma Flow. Talso, Crosley, Clark.

App. B.

COPIES OF COMPLETED PROJECT REPORTS

D

SILICA CONTENT OF DUST FROM TANK RANGES[1]

by

C. A. Kruse, 1st Lt., MC, P. H. Carey, Tech 4 and D. J. Howe, Tech 3

from

Armored Medical Research Laboratory
Fort Knox, Kentucky, January 14, 1947

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[1] Sub-project under Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks (A.M.R.L.-57). Approved by CG, ASF, 31 May 1946.

Project No. 57
MEDEA

14 January 1947

ABSTRACT

SILICA CONTENT OF DUST FROM TANK RANGES

OBJECT

Men engaged in tank operations are exposed to many potential hazards. Among these is the problem of dust. In a previous report the dust concentration to which armored personnel is exposed on maneuvers in the Fort Knox area was found to be quite high (187 to 700 million particles per cubic foot). The type of dust was not determined and, hence, the amount of free silica of a damaging character, especially those particles 10 to 3 microns or less in diameter, is not known.

Dust was collected from surface soil on dry tank ranges and from within tanks on maneuvers in the Fort Knox area. The surface soil was analyzed for free and total silica, the air-borne dust for particle size distribution and content of free silica.

RESULTS

The results to date are listed below:

1. Surface soil samples from two tank ranges have a high concentration of silica with an average of 74.3% total silica and 63.9% free silica.

2. The tank dust averages 21.5% by weight of particles below an equivalent diameter of three (3) microns, of which 10% is free silica.

3. These particles of free silica less than three (3) microns in diameter average 2.2% by weight of the total dust.

CONCLUSIONS

This content of silica of a damaging character in air-borne dust is regarded as high but the data do not permit conclusions as to whether inhalation of silica particles of such concentration and particle size distribution constitutes a medical menace to operating armored personnel.

RECOMMENDATIONS

None.

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SILICA CONTENT OF DUST FROM TANK RANGES

I. INTRODUCTION

A. Object and Background.

Men engaged in tank operations are exposed to many potential hazards. Among these is the problem of dust. In a previous report (1) from this laboratory it was established that, in the Fort Knox tank training areas which contain the highest concentration of dust, the count within and without tanks moving on a dry range at about ten miles per hour varied from 187 to 700 million particles per cubic foot.

This concentration is extremely high, but the type of dust was not determined. Accordingly, the investigation was extended to include analyses of surface soil from tank ranges and the air-borne dust in tanks on maneuvers for (1) particle size distribution, and (2) content of free and total silica.

II. EXPERIMENTAL

A. Materials, Collection.

1. Surface soil from dry tank ranges in recent use was collected at 150 to 200 yard intervals.

2. Air-borne soil was collected from the interior and, usually, in the front of tanks driven in the dust cloud of a preceding tank. Usually, an 8 to 9 gram sample was obtained. The dust laden air was drawn through a reduced pressure filter box* (filtering area about 300 square inches) consisting of two filter beds of salicylic acid crystals supported by two 120-mesh copper screens. The filter was activated by the exhaust blower of an M4A3 tank and mounted within a tank. Only particles less than about 150 microns in diameter were trapped by this method.

B. Procedures, Methods.

The surface soil was analyzed for free and total silica, the air-borne dust for particle size distribution and the percentage of free silica in each particle size range and in the total sample.

1. The alpha quartz (free silica) content of surface soil was determined spectrographically by the Bureau of Mines Laboratory, Pittsburgh, Pennsylvania.

2. The alpha quartz of air-borne soil was determined as follows: First, the dust collected in the filter box was removed by dissolving the

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*Box design obtained from Committee of Industrial Hygiene, Mellon Institute, Pittsburgh, Pa.

salicylic acid in anhydrous methanol and suction filtering the suspension through a No. 50 Whatman filter paper. The filtrate gave no evidence of sedimentation over a period of 72 hours, but did appear a reddish-brown in color. The filter cake and paper were oven-dried at 110° C. for 4 hours and the cake then removed from the paper and dried further for 20 hours. The filter cake was analyzed for free silica by the Bureau of Mines Laboratory, Pittsburgh, Pennsylvania.

3. The total silica content of surface soil was determined chemically by a standard method (2) with some modifications. The collected samples were air-dried in the laboratory for 24 hours. The sample was then ground in a mullite mortar and 1.5 to 2.0 grams were used for the analysis. The sample was placed in a 20 ml. platinum curcible and 10 grams of anhydrous sodium carbonate (Na_2CO_3) was mixed with the sample. The mixture was fused over a Meker burner. After CO_2 elimination had ceased, the crucible was cooled to room temperature and placed in a 600 ml. beaker. 120 ml. of 1-1 hydrochloric acid was used to dissolve the melt. The solution was evaporated to dryness over a hot plate. To the residue was added freshly mixed acetic anhydrate (65 ml.), water (55 ml.). The suspension was heated on the hot plate until it foamed strongly; it was removed and cooled slightly; then 1-1 HCl was added until the solution was canary yellow in color (5-15 ml.). The solution was warmed and 120 ml. of distilled water added. The suspension was filtered on fine ashless paper and washed with cold water. After impurities were removed the paper and precipitate were ignited and heated to constant weight. To the silicon dioxide residue was added 4 ml. water, 5-6 drops of concentrated sulfuric acid, and then slowly 6 ml. of 48% hydrofluoric acid. The solution was evaporated to dryness on a hot plate and the crucible heated to constant weight. The loss in weight was silicon dioxide.

4. Particle size distribution in air-borne dust samples on a weight basis was determined by the pipette sedimentation separation method (3). The oven-dried sample of air-borne dust (1½ to 2% of the fluid by weight) was dispersed in a solution containing 40 cc. sodium metasilicate stock solution (10 gm. per liter of water) and approximately 400 cc. distilled water. The dispersion was carried out in a Waring mixer for a period of 20 minutes. The dispersion was then cooled under tap water to room temperature and distilled water added to make a volume of 500 cc. This suspension was then added to a pipette apparatus which consisted of a chamber (1000 ml. hex base graduate cut off 28 cm. from the base), three stationary calibrated pipette tubes 0.15 cm. I.D., whose depths from the starting level of the liquid are 4 cm., 10 cm. and 19 cm., and joined by a suitable stopcock to a calibrated pipette of 10 ml. volume. The apparatus was inverted several times and then clamped in a water bath. At suitable time intervals samples were removed by means of the pipettes and discharged into weighed porcelain crucibles. These samples were evaporated on a hot plate to dryness and then heated in an oven at 140° C. for 2 hours before re-weighing.

a. The maximum size of the particles remaining in suspension at the time each sample was withdrawn was calculated from the following equation derived from Stokes' Law:

$$d = \sqrt{\frac{307\ (u)\ (h)}{(ps - p)\ (t)}} \quad \text{where}$$

d = diameter particle--micron
u = fluid viscosity--cps (0.8983)
h = height of fall--cm (19.09)
ps = density of solid--gm/cc (2.651)
p = density of fluid--gm/cc (0.9952)
t = time of fall--minutes (1.5)

For example, when the test is conducted with the values indicated above,

$$d = \frac{(307)\ (0.8983)\ (19.09)}{(2.651 - 0.9952)\ (1.5)} = \quad 46 \text{ microns}$$

b. The concentration of the particles remaining in suspension at the time each sample was withdrawn was computed:

$$Gc = \frac{(100)\ (Vc)\ (w)}{(Vp)\ (W)} \quad \text{where}$$

Gc = percentage of particles under d-microns remaining in suspension
Vc = starting volume of suspension--cc (587.5)
Vp = volume of sample withdrawn--cc (11.56)
w = weight of solids in Vp (corrected for dispersing agent)--gm (0.1415)
W = dry weight of sample in Vc--gm (7.1095)

Again, when computation is made using the data inserted above,

$$Gc = \frac{(100)\ (587.5)\ (0.1415)}{(11.56)\ (7.1095)} = \quad 97.8\%$$

A plot of cumulative percentage under size d-micron versus diameter allows interpolation of the amount below any particle size.

5. The per cent of free silica of the various samples withdrawn for determination of particle size and weight distribution was determined at the Bureau of Mines, Pittsburgh, Pa. (and corrected locally for the dispersing agent).

C. Results.

Table I shows the concentrations of total and free silica in the surface soil of two tank ranges. The soil averages 74.3% total silicon dioxide and 63.9% free silica, or the free silica averages approximately 86% of the total silica.

TABLE I

Amount of Total and Free Silica in Surface Soil of Fort Knox, Kentucky

Sample Number	Date Obtained	Total Silica--Per Cent		Free SiO_2--Per Cent
		Air Dry Basis	Mineral Basis	
4	May 1946	69.5	--	58
5	"	70.0	--	56
6	"	71.6	--	53
7	"	68.0	--	62
8	"	71.2	--	61
9	"	73.8	--	63
10	"	73.4	--	66
11	"	71.8	--	58
12	June 1946	74.5	80.0	67
13	"	77.0	82.1	69
14	"	78.8	84.0	72
15	"	77.0	82.0	70
16	"	78.4	82.7	65
17	"	78.0	82.7	66

In Fig. 1 are plotted the data for air-borne soil particle size and distribution according to weight as calculated under methods. The distribution for the two tank ranges is almost identical and the graph indicates that the dust contains approximately 22% by weight of particles below an equivalent diameter of three (3) microns, and 33% by weight of particles less than 10 microns.

FIG 1

AIRBORNE SOIL PARTICLE SIZE ANALYSIS

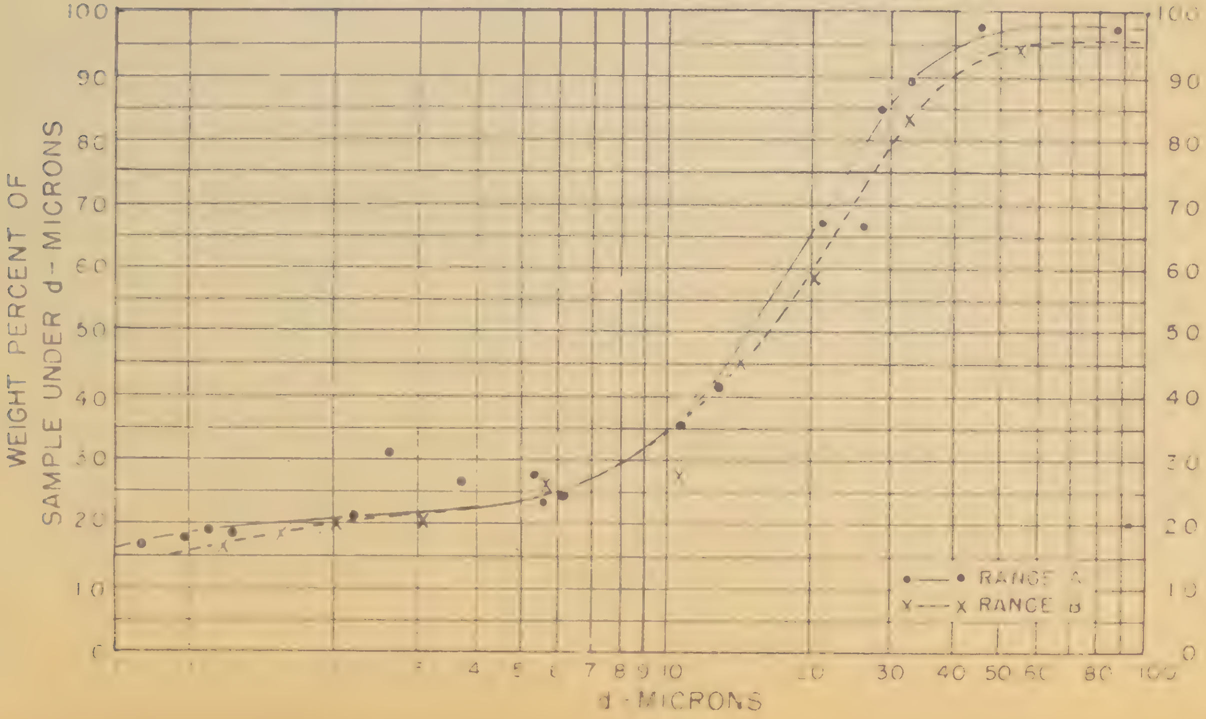


Fig. 2 represents the percentage of alpha quartz in each particle size range of air-borne dust. This graph was constructed by plotting the percentage of free silica of the various samples in Methods 5 against the equivalent diameter of each size fraction as obtained in Methods 4a. It is apparent that particle sizes three microns or less in diameter contain 10% of alpha quartz by weight, despite the fact that as particle size decreases the percentage of alpha quartz also decreases.

FIG. 2

ALPHA QUARTZ CONTENT OF AIRBORNE SOIL

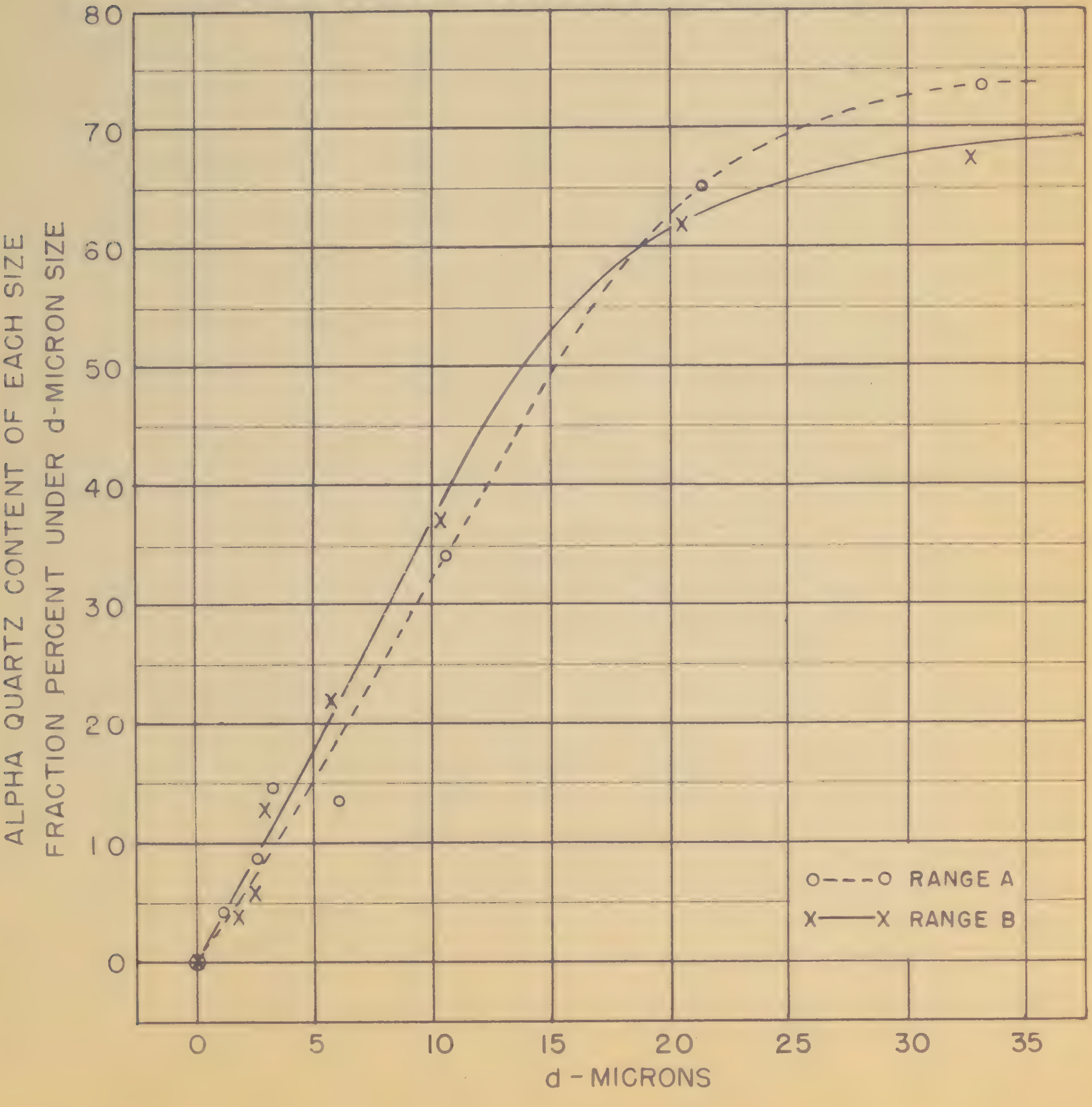
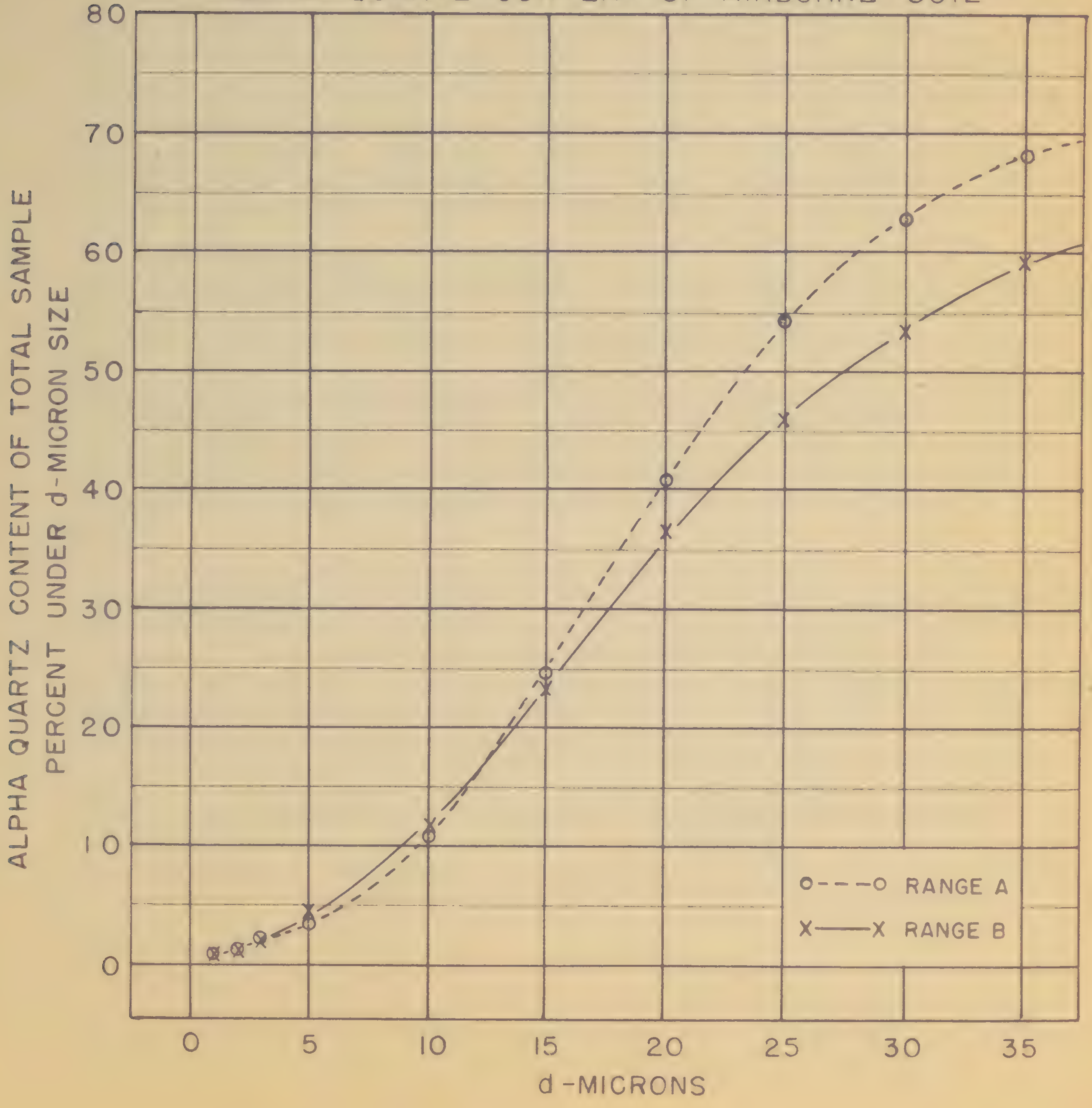


Fig. 3 shows the percentage of the total sample of air-borne dust that is alpha quartz. The points were obtained by coupling the values in Fig. 2 with the weight percentages (Gc) from the particle size distribution curve (Fig. 1). The graph indicates that air-borne dust contains an average of 2.2% alpha quartz by weight of particles less than three (3) microns in diameter, and 11% of particles less than ten (10) microns in diameter.

FIG. 3

ALPHA QUARTZ CONTENT OF AIRBORNE SOIL



III. DISCUSSION

The results indicate that at Fort Knox the dust concentration in tanks is extremely high and that the surface soil and air-borne dust have a high concentration of free silica, particularly of the clinically dangerous dust composed of small particles with equivalent diameters below ten (10) to three (3) microns.

The variation of quartz content with particle size is of particular interest. Although the quartz particles less than three (3) microns diameter constitute only 2.2% of the total particles by weight, this small percentage represents a tremendous number of particles in a small mass of material. For example, if we assume perfect spherical shape for particles, 1,000,000 quartz particles of three (3) micron diameter would weigh only 0.000013 gm., and the same number of ten (10) micron particles would weigh 0.0014 gm., so that for the same gross weight the three (3) micron particles would be 100,000,000 in number. Thus, the data in Fig. 3 indicate that there are about 25 times as many particles three (3) microns or less in diameter as compared to those ten (10) microns or less in size.

These observations raise the question whether such dust is a medical hazard. According to Lanza (3), where a highly silicious dust is involved (approximately 80% free silica), a total concentration of 5,000,000 particles per cubic foot of air is dangerous. Although the percentage of free silica found in the air within tanks is somewhat lower (64%), the total particle concentration of 137-700 million particles per cubic foot, with a relatively large complement less than three (3) microns in diameter, suggests the possibility of ultimate silicotic pathology. However, it is not to be inferred that such exposure among armored personnel will lead to silicosis unless there is demonstrated an associated adequate duration and constancy of exposure.

In this connection, mention may also be made of the fact that at Fort Knox the morbidity rate for respiratory infections is apparently much greater than at Camp Atterbury (5). For example, for the weeks ending August 24 and September 17, 1945, comparisons of the case rates per 1000 men at the two installations were 129 versus 44, and 119 versus 25. Both installations have essentially the same geological, climatic conditions and had, at the time, approximately the same mean strength of men, but differ in that Fort Knox is a tank training center while Atterbury is an infantry center. If it can be established that the much greater incidence of respiratory infections at Fort Knox is largely restricted to tank personnel participating in maneuvers, then the dust exposure considered here must be regarded as a possible contributing factor to the greater morbidity rate. However, until such time as additional data are available, this must be considered as mere speculation.

IV. CONCLUSIONS

In the Fort Knox tank training areas analyses have been made of surface soil and air-borne dust in tanks on maneuvers. The results are: (1) Surface soil samples from two distant tank ranges have a high concentration of

silica with an average of 74.3% total silica and 63.9% free silica. (2) The air-borne dust within tanks from the same two tank ranges contains an average of 21.5% by weight of particles below an equivalent diameter of three (3) microns. (3) Of the particles of air-borne dust less than three (3) microns in diameter, 10% is free silica. (4) These particles of free silica less than three (3) microns in diameter constitute 2.2% by weight of the total dust.

The question is raised whether such a concentration of highly siliceous dust, especially in the dangerous sizes less than ten (10) microns or three (3) microns in diameter, constitutes a medical hazard to operating armored personnel.

V. RECOMMENDATIONS

None.

VI. BIBLIOGRAPHY

1. Project 4-1, "Dust Exposure in Armored Vehicles. Final Report on Sub-project 4-1, Determination of Dust-Loads and Characteristics of Dusts Encountered in Operation of Armored Vehicles," by Theodore F. Hatch, Lt. Col., SnC, and Robert H. Walpole, Capt., FA., A.M.R.L., Fort Knox, Kentucky.

2. Scott's Standard Methods of Chemical Analysis. 5th Edition. Vol I, page 794.

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4. H. A. Lanza and Jacob A. Goldberg, Industrial Hygiene, 1939. Oxford Medical Publications.

5. Weekly Weather Report of the Office of the Surgeon General, Vol 5, Report No. 34.

EFFICIENCY OF SIGNAL CORPS OPERATORS IN EXTREME COLD[1]

by

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from

Armored Medical Research Laboratory
Fort Knox, Kentucky, January 22, 1947

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[1] Sub-project under Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks (AMRL-57) approved by Commanding General, ASF, 31 May 1946.

Project No. 57
MEDEA

22 January 1947

ABSTRACT

EFFICIENCY OF SIGNAL CORPS OPERATORS IN EXTREME COLD

OBJECT:

At the request of the Signal Corps, experiments were designed to test the effect of wearing issue arctic clothing and of exposure to extreme cold while wearing arctic clothing on the efficiency of Signal Corps men operating representative Signal Corps equipment.

PROCEDURE:

Four Signal Corps operators were detailed to the AMRL and their performance tested on the following equipment:

Radar Trainer BC-968-A - Error in tracking integrated over a three-minute period.

Radio SCR-694-C - Time required to change frequency and resume voice transmission.

Switchboard BD-72 - Time required for the manual operations in completing a call through the switchboard.

After a three week period of training, a routine was established in which each subject operated each of the three sets of equipment for fifteen-minute periods during each hour of testing. During the mornings normal values were obtained at 23°C with fatigue uniform and then with the same conditions except that a mitten assembly was worn. In the afternoons the subjects wore complete arctic clothing including the mitten assembly and worked for three hours at ambient temperatures that were lowered from -25°C to -41°C on successive days.

RESULTS AND CONCLUSIONS:

(1) Radar Trainer BC-968-A and switchboard BD-72, without modification can be operated while wearing mittens, arctic, with two wool inserts and, over-whites, outside. It is necessary to first remove the protective grill of Radio SCR-694-C before it can be operated with mittens.

(2) The radar trainer can be operated as efficiently with mittens as bare-handed. Radio and switchboard operators are less efficient when wearing mittens although considerable improvement was gained by training with mittens at comfortable temperatures.

(3) Efficiency with each instrument is still lower when arctic clothing is worn and men are exposed to low temperatures in the cold room. The immediate loss of efficiency is at least partly due to the cumbersome arctic clothing, but there are probably other unidentified factors.

(4) Efficiency with the radio and switchboard showed only negligible change

during any three-hour exposure period. When, on successive days, ambient temperature was lowered from -25°C to -41°C no associated change in efficiency could be demonstrated.

(5) Efficiency with the radar trainer was generally lowest during the second hour of exposure. Performance on different days was poorer with lower ambient temperature. Part of the effect of cold on efficiency is related to the discomfort produced, even through mittens, by contact with the cold metal control handle.

(6) With ambient temperatures of -40°C and a wind velocity of 3-5 mph, men protected by arctic clothing as now issued and allowed to exercise become uncomfortably cold after one and one-half hours and after two and one-half hours may have dangerously cold hands and feet. Usually, by taking as much exercise as their duties would permit, they were able to withstand an exposure of three hours without injury.

(7) Arctic clothing as now designed affords least adequate protection for hands and feet of Signal Corps men while operating their equipment at extremely cold ambient temperatures.

RECOMMENDATIONS:

(1) That Signal Corps operators be taught to work wearing mittens whenever practicable.

(2) That Signal Corps equipment be winterized so as to permit:

(a) Operation while wearing mittens (e.g., the protective grill of radio SCR-694-C should be removed or modified).

(b) Considerable freedom of the operators so that they can exercise during operations (e.g., lengthen head-phone extension cords for radio and switchboards).

(3) That consideration be given to the modification of metal control handles in order to reduce operator discomfort during continuous cold-weather operations.

(4) That the problem of more adequate protection of the hands and feet from extreme cold be actively investigated.

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EFFICIENCY OF SIGNAL CORPS OPERATORS IN EXTREME COLD

I. OBJECT: The objects of these experiments were to test (1) the effect of arctic clothing and (2) the effect of extreme cold while wearing arctic clothing, on the efficiency of representative Signal Corps men while operating representative Signal Corps equipment.

II. EXPERIMENTAL:

A. Materials and Equipment.

(1) Signal Corps Equipment. The following equipment was selected, winterized and sent to the AMRL by the Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey, as representative types of Signal Corps equipment.

(a) Radar Trainer BC-968-A. An instrument designed to train future radar operators. As in actual radar tracking, the operator observes two pulses on the screen of an oscilloscope. Course cams supplied with the machine maneuver the pulses in a pattern similar to radar tracking under service conditions. Difference in height of pulses indicates an off-target position and this can be corrected by properly rotating a hand wheel attached to the trainer. Off-target deviations are recorded in the form of an ink line on a strip chart in which deviation of the recorded line from the center of the chart is proportional to the degree to which the operator is off-course. (Figure 4.) A counter serves as an integrator and records a numerical score which corresponds to the total tracking error. The machine is adjusted so that each tracking run lasts three minutes. The most difficult course cam, number 6, was used. The machine was set for azimuth operations only and attachments for interference, noise and fading were not used. The trainer was calibrated at the beginning and end of each morning and afternoon experiment. For details, see Appendix I, paragraph A.

(b) Radio Set SCR-694-C, a portable receiver-transmitter. Microphone T-17 was used. Electrical power was furnished by Vibrator Power Supply PE-237 connected to a 12 volt storage battery kept outside of the cold room. An electrical time clock was used to measure the time required for the operator to change to a new frequency and notify the observer by voice transmission on that new frequency that he had completed the prescribed operations including manipulating dials and switches sixteen times and zero beating three times. In order to operate the radio while wearing mittens it was found necessary to first remove the protective grill. For details of radio operations, see Appendix I, paragraph B.

(c) Switchboard BD-72, a lightweight, twelve-line, field telephone switchboard. Telephone EE-8-A was used. By means of a selector switch and either of two telephones, the observer could signal any of the twelve lines of the operator's switchboard. Lines from the two halves of the switchboard were paired at random by means of six colors. The operator was required to complete the call through his switchboard by connecting the signaled line with the other line designated by the same color. This method of signaling the operator was devised in order to leave out the undesirable complication of voice instruction, as "Dexter, three". The interval required for the manual operations entailed in completing the call through the switchboard was timed by an electric time clock in a thyratron activated relay circuit (see Appendix I, paragraph C).

(2) Special Equipment.

(a) Standard Electric Time Clock, Model S1, manufactured by Standard Electric Time Company, Springfield, Massachusetts. Accurate to within 0.01 seconds.

(b) Thyratron activated relay circuit for time clock control. See Appendix I, paragraph C, for wiring diagram.

(c) Potentiometer, galvanometer and constantan-copper thermocouples.

(d) Cold room, 12,000 cubic feet capacity, cooled by a two-stage ammonia compressor.

(3) Clothing.

Three different combinations of issue clothing were worn.

(1) Herringbone-twill fatigue clothing.

(2) Fatigues plus a mitten assembly consisting of mittens, arctic, with insert, mittens, wool insert, trigger finger, and mittens, overwhite. Nylon inserts were not worn.

(3) Full arctic clothing including the mitten assembly.

See Appendix II, for detailed list of arctic clothing.

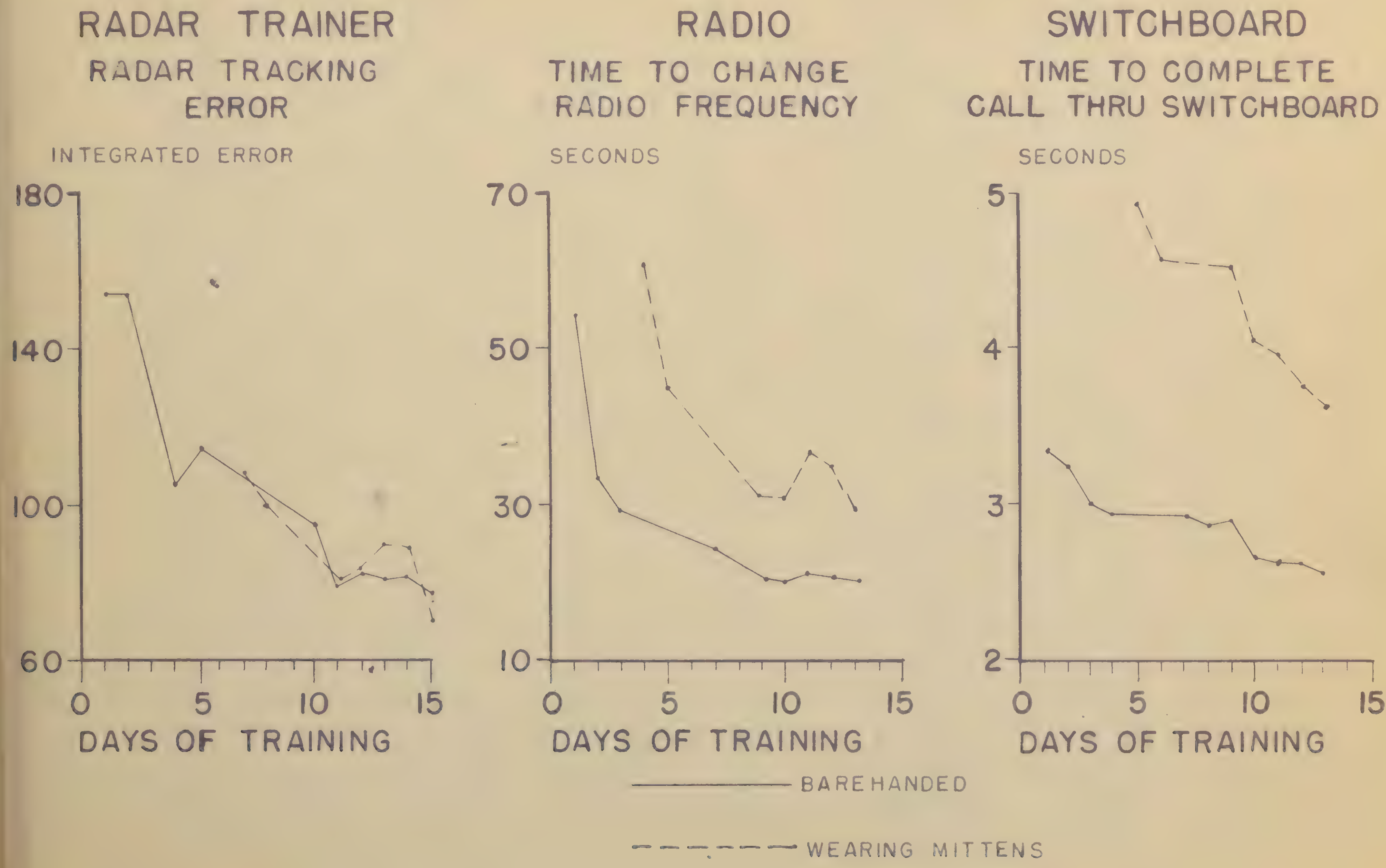
Clothing outfits 1 and 2 were worn while obtaining controls at comfortable laboratory temperatures and outfit 3 was worn during all cold room work.

B. SUBJECTS:

Four healthy young men, all 19 years of age, were selected by the Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey, as representative Signal Corps operators and were detailed for one month to the AMRL to be used as test subjects.

FIGURE 1

AVERAGE LEARNING CURVES
FOUR SUBJECTS
FATIGUE UNIFORM, AMBIENT TEMPERATURE 23°C



Their individual Signal Corps training is enumerated in Appendix III. AMRL personnel served as recorders.

C. PROCEDURE:

The subjects gained proficiency in the operation of the equipment during the first three weeks. During the fourth week the data presented in Table I was obtained. During this last week a routine was established in which each subject operated each of the three sets of equipment during each hour of testing. This procedure enabled each man to complete each hour about thirty calls through the switchboard, to change frequency on the radio ten to fifteen times and to make three or four tracking runs with the radar trainer.

Each day included five hours of testing. The first two hours the men wore fatigues and during one of the hours operated the equipment barehanded and during the other hour operated the equipment while wearing the mitten assembly. The data obtained during these two hours, at the laboratory temperature of 23°C, were used as controls.

The third, fourth and fifth hours, in the afternoon, were spent in the cold room. The subjects wore complete arctic clothing including the mitten assembly (See Appendix II). Cold room temperature was lowered on successive days from -25°C to -41°C with a mean deviation of no more than ± 2°C on any day. Wind velocity ranged between 3-5 miles/hour.

As a safeguard against the possibility of frost bite during cold room work, skin temperatures of the right thumb and left great toe of some of the subjects were checked by means of thermocouples.

D. RESULTS:

Although the four test subjects had attended various Signal Corps schools, it was soon apparent that additional practice would greatly improve their performance. This is illustrated for radar trainer BC-968-A in Figure 1. As shown, improvement at first was rapid, but after the tenth day showed little change. It will be noted that the mitten assembly produced no change in performance even when first worn.

Figure 1 also illustrates the improvement in radio operation that came with continued practice, and here too, there was but little improvement after the tenth day. When mittens were first worn they constituted a marked handicap which was quickly reduced by further practice with mittens at laboratory temperatures.

Switchboard performance showed less improvement with practice (Figure 1) than did radar trainer and radio operation. Mittens, however, resulted in a considerable increase in time required to complete each call. Performance while wearing mittens continually improved with practice.

In Table 1 are tabulated the average scores made on each machine during the last five days of the experiment. These scores show that at comfortable laboratory temperatures the integrated error on the radar trainer was the same whether the operator worked barehanded or with mittens. Whenever the trainer was operated in the cold room the error was always significantly greater.

TABLE I

TEST SCORES
SIGNAL CORPS EQUIPMENT

	CONTROLS TEMPERATURE 23°C FATIGUE UNIFORM		COLD ROOM EXPOSURE TEMPERATURE -25° TO -41°C FULL ARCTIC CLOTHING		
SUBJ	HANDS BARE	MITTEN ASSEMBLY	FIRST HOUR	SECOND HOUR	THIRD HOUR
		RADAR TRAINER - INTEGRATED ERROR			
JJR	63	63	90	101	99
BAC	97	102	123	173	145
RAS	77	77	114	124	122
LJL	95	94	140	165	131
Avg	83	84	117	141	124
		RADIO SECONDS TO CHANGE FREQUENCY			
JJR	25	38	50	56	45
BAC	23	35	50	52	43
RAS	21	30	37	41	38
LJL	17	28	32	34	37
Avg	22	33	42	46	41
		SWITCHBOARD SECONDS TO COMPLETE CALL			
JJR	2.99	4.07	5.15	4.89	5.25
BAC	2.53	3.44	4.22	4.50	4.45
RAS	2.81	4.02	4.85	4.89	4.76
LJL	2.65	4.58	5.47	5.62	5.85
Avg	2.75	4.03	4.92	4.98	5.08

A table of the average scores made on Signal Corps equipment by each of the four subjects during the final five days of the experiment. Controls were run in the mornings and cold room scores were made during a three-hour exposure each afternoon.

On the radio, mittens increased by one-half the time required for a frequency change. An additional increase occurred when the subjects entered the cold room and this value remained constant throughout the exposure period.

Switchboard operation time was also significantly increased by mittens and further increased by cold room exposure. As with the radio, switchboard scores varied negligibly throughout the three hours of cold room exposure.

No constant change in radio and switchboard scores occurred when the ambient temperature was lowered on successive days. (Figure 3). The integrated error on the radar trainer, however, was generally higher at lower ambient temperature. This trend was apparent even during the first hour of cold room exposure.

Subjective reactions of the operators during their daily three-hour cold room exposure periods were rather constant from day to day. The first hour of exposure the subjects were comfortable but from the early part of the second hour complained of cold hands and feet and throughout the third hour these parts were uncomfortably cold. Thumb and toe skin temperatures as low as 1°, 1.5° and 3°C were registered. On two occasions, subjects' hands and feet became so painfully cold that they were ordered out of the cold room at the end of two and one-half hours. Shivering was never observed. After the first hour, operation of the radar trainer always chilled the operator's thumb that was grasping the metal handle of the control wheel and at times this thumb became so painfully cold and stiff that it prevented effective operation of the trainer. The subjects discovered that muscular activity helped them stay warm and throughout the last hour and one-half of cold room exposure voluntarily exercised whenever their duties would permit.

III. DISCUSSION:

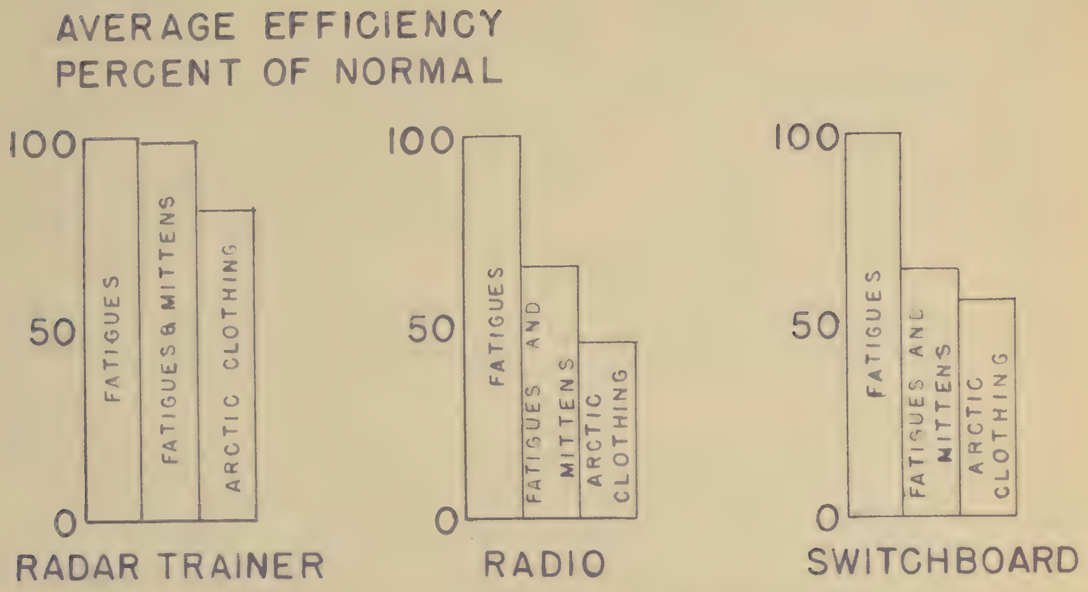
From the above scores it is apparent that mittens interfered with operation of Signal Corps equipment (except the radar trainer) and that full arctic clothing interfered even more. In order to best compare the effect of mittens, arctic clothing and cold room exposure on the operation of the three different pieces of equipment, it was found convenient to first convert the absolute scores into "Per Cent Efficiency of Normal Performance". This was done according to the following formula:

$$\begin{array}{c}\text{Average Efficiency}\\ \text{Per Cent of Normal}\end{array} = \frac{\text{Average score standard conditions}}{\text{Average score wearing mittens, etc.}} \times 100$$

Thus, the subjects, when wearing fatigues and mittens at comfortable laboratory temperatures, operated the radar trainer at 100% efficiency, the radio at 65% efficiency and the switchboard at 69% efficiency. These are average efficiencies for the last five days of the experiment only, as the radio and switchboard efficiencies were much less when mittens were first worn. (See Figure 2 for a representative day). Training with mittens on these two latter machines at comfortable laboratory temperatures produced marked improvement in performance in a few days and improvement with the switchboard was continuing even at the end of the experiment. At no point did wearing mittens reduce efficiency of radar trainer operations. (Figure 1). Training schedules for such equipment as the radio and

FIGURE 2

EFFECT OF MITTENS AND ARCTIC CLOTHING ON EFFICIENCY OF OPERATION OF SIGNAL CORPS EQUIPMENT



Average efficiency, per cent of normal, of the four subjects on a representative day while working in fatigues at 23°C with and without mittens and for the first hour of work at -15°C while wearing full arctic clothing (no subjective feelings of coldness).

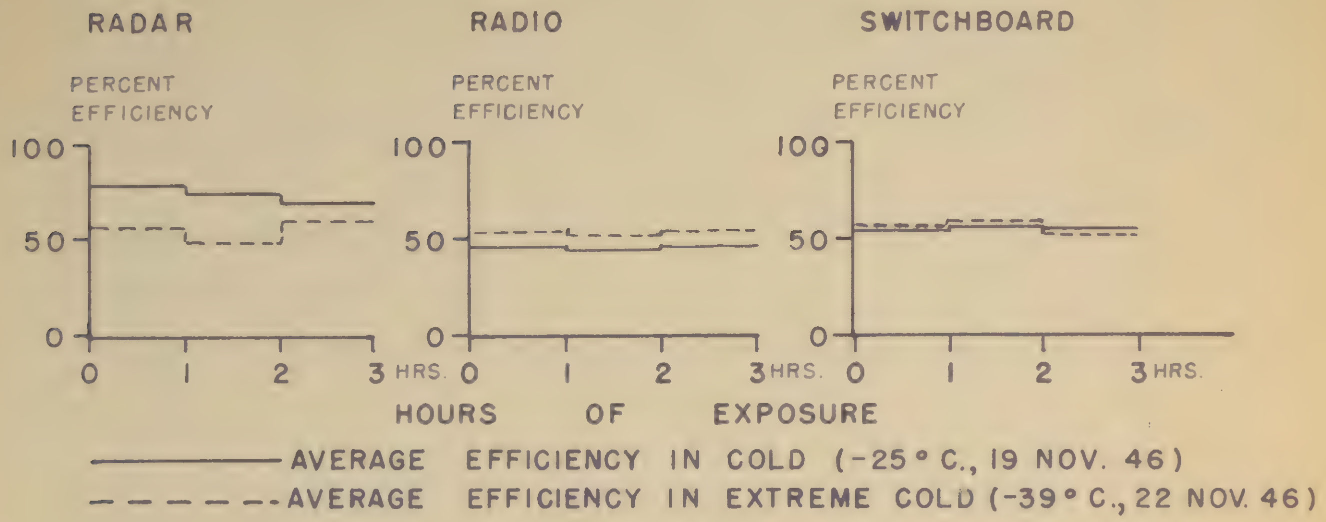
switchboard should include periods of operation at mild temperatures while wearing mittens.

As the operators had no subjective feelings of coldness during the first hour of their cold room exposure, the decrease in efficiency this hour is believed to principally reflect the cumbersomeness of arctic clothing. (See Figure 2). During the second and third hours the operators always complained of cold hands and feet, complaints substantiated by skin temperature measurement, and results for these two hours include any effect of cold in addition to the necessity for wearing bulky clothing.

During the first hour of cold room exposure, the radio was operated at an average of 51% efficiency and the switchboard at an average of 57% efficiency. Efficiency with these two machines did not vary significantly during the second and third hour of any exposure period nor with the lowering of ambient temperatures on successive days. (See Figure 3). The reason that cold extremities did not lower efficiency is thought to be that the mittens were so cumbersome that they completely masked tactile sensation and prevented fine finger motions, permitting only grasping between the thumb and fingers. Thus little change in performance occurred when fingers became cold and stiff, as most of the required motions were made from the wrist, elbow and shoulder joints and tactile sensation had already been

FIGURE 3

EFFECT OF AMBIENT TEMPERATURE ON EFFICIENCY



Average efficiency of four subjects on two representative days illustrating that radio and switchboard performances were identical in cold and very cold environments, while radar trainer efficiency was lower at lower ambient temperatures. As on these two days, radio and switchboard performance varied negligibly throughout the three hours of any exposure period. Radar trainer efficiency was usually lowest the second hour.

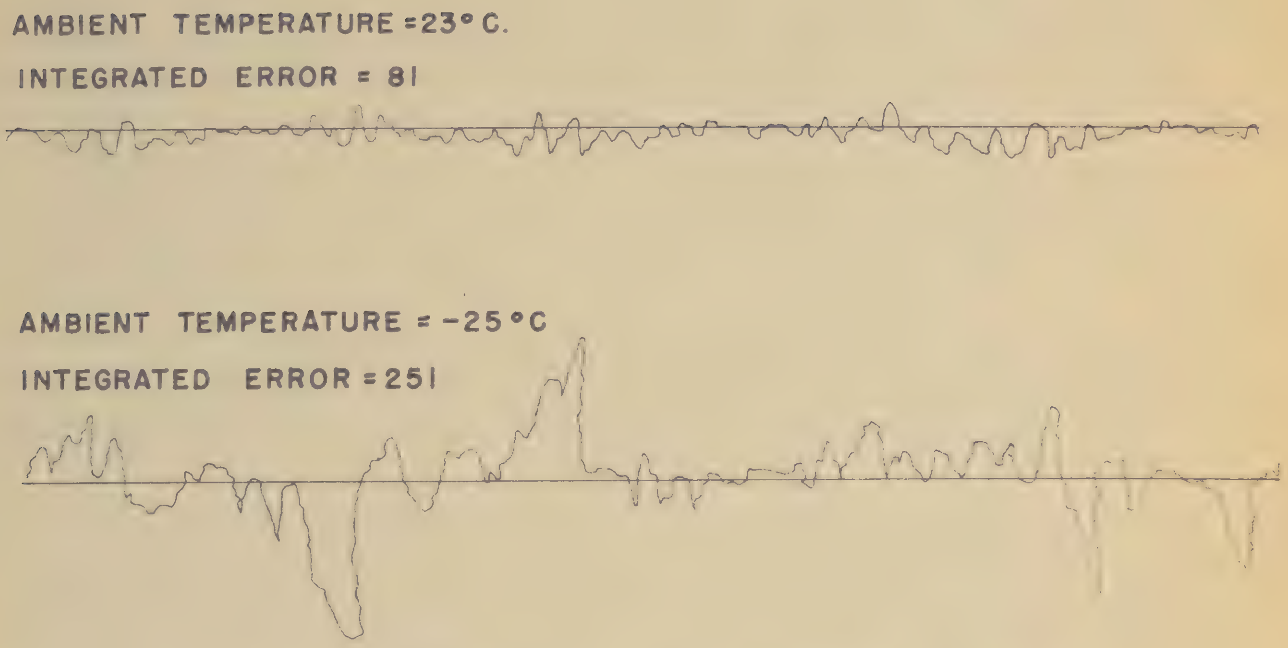
masked. Extreme chilling of the hands, as occasionally happened when operating the radar trainer, prevented effectual grasping of objects.

Radar trainer performance differed from that with the radio and switchboard, as efficiency the first hour of cold room exposure on successive days decreased from 81% to 60% with a drop in ambient temperature from -25° to -41°C. On any particular day efficiency was usually lowest the second hour. (See Figure 3). Although other factors were probably involved, such as the increase from one to two pounds in maximum handwheel tension and a slowing of response by the commutator variable contact which was not reflected in calibration values, part of this decrease in efficiency was due to the marked chilling of the operator's thumb by the metal control wheel handle. Thumb chilling was most painful the second hour of exposure and at times resulted in the operator temporarily losing control of the hand wheel. (See Figure 4). It was generally during the second hour that radar trainer efficiency was lowest.

Electrical heating or an insulating covering of any metal control handle requiring prolonged contact at cold temperatures seems desirable in order to maintain the operator's hands at a safe temperature.

FIGURE 4

EFFECT OF THUMB CHILLING ON RADAR TRAINER OPERATION



A reproduction of the strip charts from two tracking runs by subject LJL on 19 November 1946. (Deviation from center is proportional to the tracking error). The top graph is from a control run with the subject dressed in fatigues and working at an ambient temperature of 23°C. Integrated error = 81. The bottom graph represents the subject's third tracking run during the second hour of exposure to an ambient temperature of -25°C. Integrated error = 251. Previous contact with the cold metal control wheel had left the operator's thumb so stiff that he could no longer effectually grasp the control wheel and a large tracking error resulted.

IV. CONCLUSIONS:

(1) Radar Trainer BC-968-A and switchboard BD-72 without modification, can be operated while wearing mittens, arctic with two wool inserts and, overwhites, outside. It is necessary to first remove the protective grill of Radio SCR-694-C before it can be operated with mittens.

(2) The radar trainer can be operated as efficiently with mittens as bare handed. Radio and switchboard operators are less efficient when wearing mittens although considerable improvement was gained by training with mittens at comfortable temperatures.

(3) Efficiency is still lower when arctic clothing is worn and men are exposed to low temperatures in the cold room. The immediate loss of efficiency is at least partly due to the cumbersome arctic clothing, but there are probably other unidentified factors.

(4) Efficiency with the radio and switchboard showed only negligible change during any three-hour exposure period. When, on successive days, ambient temperature was lowered from -25°C to -41°C no associated change in efficiency could be demonstrated.

(5) Efficiency with the radar trainer was generally lowest during the second hour of exposure. Performance on different days was poorer with lower ambient temperature. Part of the effect of cold on efficiency is related to the discomfort produced, even through mittens, by contact with the cold metal control handle.

(6) With ambient temperatures of -40°C and a wind velocity of 3-5 mph, men protected by arctic clothing as now issued and allowed to exercise become uncomfortably cold after one and one-half hours and after two and one-half hours may have dangerously cold hands and feet. Usually, by taking as much exercise as their duties would permit, they were able to withstand an exposure of three hours without injury.

(7) Arctic clothing as now designed affords least adequate protection for hands and feet of Signal Corps men while operating their equipment at extremely cold ambient temperatures.

V. RECOMMENDATIONS:

(1) That Signal Corps operators be taught to work wearing mittens whenever practicable.

(2) That Signal Corps equipment be winterized so as to permit:

(a) Operation while wearing mittens (e.g., the protective grill of radio SCR-694-C should be removed or modified).

(b) Considerable freedom of the operators so that they can exercise during operations (e.g., lengthen headphone extension cords for radio and switchboards).

(3) That consideration be given to the modification of metal control handles in order to reduce operator discomfort during continuous cold-weather operations.

(4) That the problem of more adequate protection of the hands and feet from extreme cold be actively investigated.

APPENDIX I

A. Calibration of Trainer BC-968-A.

At the beginning and end of each morning and afternoon series, the radar trainer was calibrated by removing the course cam and fixing the cam follower to the frame with a cap screw, so that movement of the commutator variable contact was controlled entirely by the hand wheel. The "zero position" of the hand wheel was then determined. The "zero position" was that position of the control wheel at which no error was registered during the course of a three-minute run, indicating that the variable contact was in exactly the midline of the commutator cylinder. At this point the pulses on the cathode ray screen were balanced. The variable contact was then moved by one revolution of the handwheel to the right and then to the left of the commutator midline and the score of a three-minute run in each position was recorded. The "zero postion" and one-revolution deviations were always approached from a clockwise direction in order to keep inaccuracies due to play at a minimum.

Although the "zero position" of the hand wheel varied considerably at each calibration (due to a sector gear in the hand drive unit), the sum of the integrated error produced by the two one-revolution deflections was remarkedly constant and averaged 1596 with an average deviation of only ± 19.

B. Radio Frequency Change Protocol.

In order for a series of frequency change times to contain comparable scores, each frequency change was one of 200 KC. By an appropriate motion of his hand the observer signaled to the operator whether the change would be an increase or decrease of 200 KC from the previous setting. The subject then performed the following operations on his receiver-transmitter (all switches and dials were returned to their original position following each frequency change except the frequency control):

Receiver:

PHONE-CW-NET-CAL Switch, PHONE to CAL
SENSITIVITY Switch, LOW to HIGH
Volume Control, LOW to HIGH
Tune 200 KC up or down as directed and
Zero Beat receiver to calibration
PHONE-CW-NET-CAL Switch, CAL to NET

Transmitter:

SEND-STANDBY-OFF Switch, STANDBY TO SEND
Turn CRYSTAL Switch from Crystal A to MO
POWER Switch, LOW to HIGH
Frequency Control Switch to new calibration
Zero Beat by tuning transmitter to receiver by ear
Adjust Indicator to maximum glow by aligning the two dots
CW-MCW-PHONE Switch, MCW to CW
Depress Microphone Button and
Adjust Antenna Tuning knob to maximum light
Readjust Frequency Tuning Control to Zero Beat by ear
CW-MCW-PHONE Switch, CW to PHONE

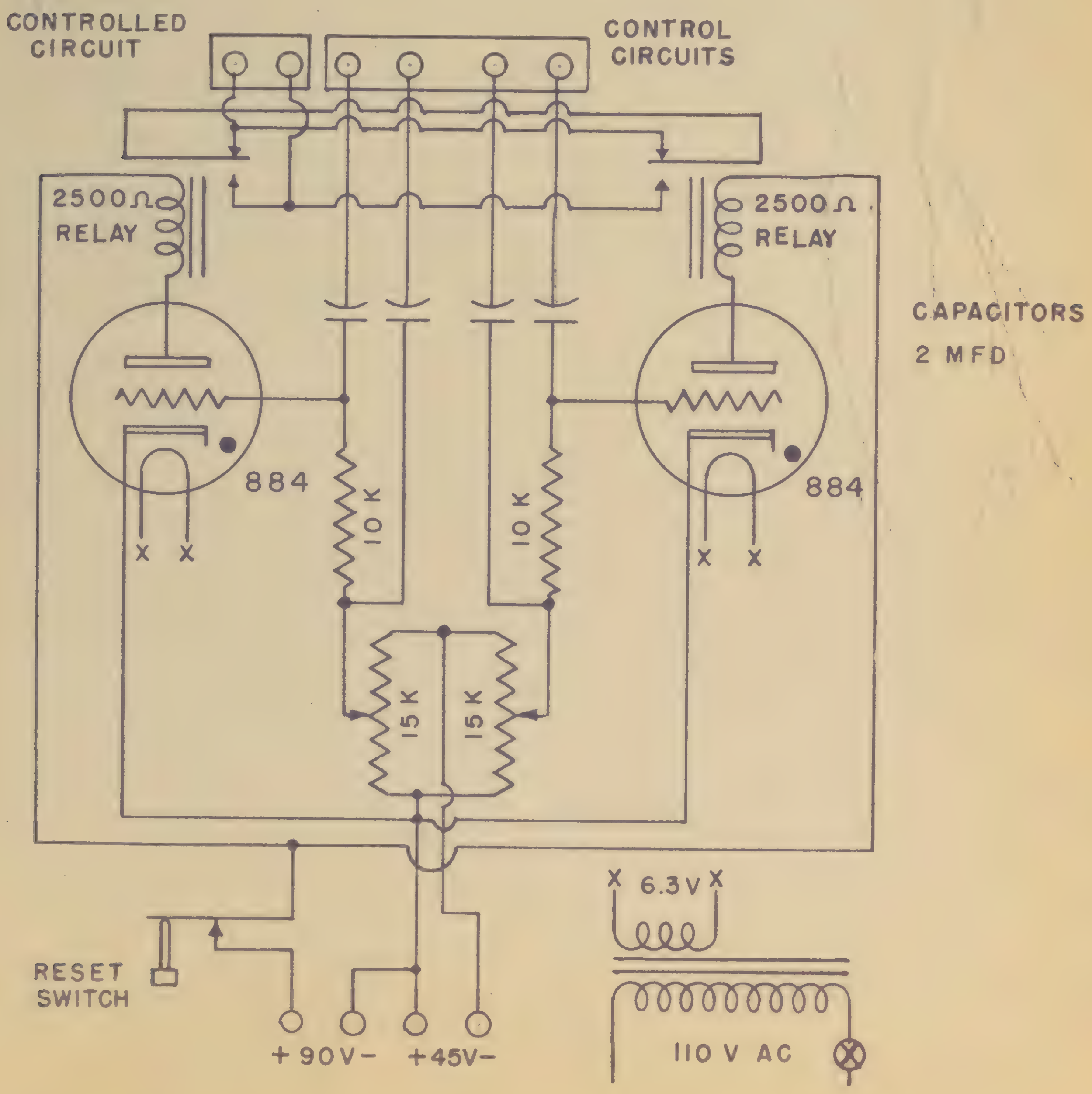
Receiver:

PHONE-CW-NET-CAL Switch,
NET to PHONE

Transmitter:

Depress Microphone
Switch and send
"Stop Clock"

C. Wiring diagram for Thyratron Relay Circuit.



APPENDIX II

The following is a list of the arctic clothing worn during all work in the cold room. All items are standard Army Issue.

1. Undershirt, wool O.D. (turtle neck)
2. Drawers, wool, O.D., long
3. Shirt, flannel, O.D., coat style
4. Trousers, field, wool, serge 18 oz. special
5. Sweater, high neck
6. Muffler, wool, O.D.
7. Trousers, field, cotton, O.D. (ankle closure)
8. Parka, field, pile, O.D.
9. Parka, field, cotton, O.D. (fits legs)
10. Parka, field, overwhite
11. Trousers, field, overwhite
12. Mask, face, cold weather
13. Socks, cushion sole, 1 pair
14. Socks, ski, white, 2 pairs
15. Socks, felt, 1 pair
16. Boots, mukluk, with 2 pair felt or jute insoles
17. Mittens, arctic, with insert
18. Mittens, wool insert, trigger finger
19. Mittens, overwhite

APPENDIX III

Qualification of Subjects

A. BAC, Pfc. - RA 38775697. Age 19 years. Height, 5 ft. 9 in., weight, 155 lbs., healthy.

Signal Corps Training: Central Signal Corps School, Camp Crowder, Mo., for three weeks. Eastern Signal Corps School, Fort Monmouth, New Jersey, for six months course in telephone and telegraph installation and repair. Signal Corps Engineering Laboratories, Development Detachment, Fort Monmouth, New Jersey, one month.

B. JJR, Pvt., - RA 12234441. Age 19 years. Height, 6 ft. ½ in., weight, 163 lbs., healthy.

Signal Corps Training: Central Signal Corps School, Camp Crowder, Mo., for 3 weeks. Eastern Signal Corps School, Fort Monmouth, New Jersey, qualifying as Central Office Technician with MOS 095. Signal Corps Engineering Laboratories, Development Detachment, Fort Monmouth, New Jersey, one month.

C. RAS, Cpl., - 44126243. Age 19 years. Height, 5 ft. 7 in., weight, 130 lbs., healthy.

Signal Corps Training: Central Signal Corps School, Camp Crowder, Mo., for four months. Eastern Signal Corps School, Fort Monmouth, New Jersey, for a four and one-half months course in telephone cable splicing. Signal Corps Engineering Laboratories, Development Detachment, Fort Monmouth, New Jersey, one month.

D. LJL, Pvt., - 43044154. Age, 19 years. Height 6 ft. 1 in., weight, 160 lbs., One eye astigmatic.

Signal Corps Training: eight months in Radio Operators School and two months at Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey.

no. 3

A CRITIQUE OF PHYSICAL FITNESS TESTS *

by

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from

Armored Medical Research Laboratory
Fort Knox, Kentucky
February 19, 1947

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* Sub-project under Studies of Fatigue in Relation to Military Tasks (AMRL-56). Approved by CG, ASF, 31 May 1946.

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[2] Collaborator from Canadian Army.

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Project No. 5b
MEDEA

19 February 1947

ABSTRACT

A CRITIQUE OF PHYSICAL FITNESS TESTS

OBJECT:

This project has three purposes: (1) To analyze data from this Laboratory on physical fitness as measured by the Harvard Step Test, the Navy Step Test, the Army Ground Forces Test and the Army Air Forces Test; (2) To discuss the difficulties in definition and measurement of physical fitness; (3) To make recommendations for the improvement of present tests and for the development of new tests.

DISCUSSION:

Since military operations require men who are physically fit it is highly desirable that some measurement or test be available to permit discrimination between degrees of fitness. Only by evaluating fitness is it possible to employ preselection logically, to measure the effects of training and to determine stages of convalescence. Since there is no universally accepted definition of physical fitness, many tests designed to evaluate it actually measure different aspects of fitness. When it became apparent that non-performance tests were thoroughly unreliable as predictors of performance, urgency of the war situation did not permit a critical study of the various elements in physical fitness which ought to be measured by an acceptable test. Practicable though empirical methods were employed without a basic study of how well they actually measured the sum total or discriminated between the several component parts of physical fitness. As gross errors became apparent changes were introduced into the tests or scoring systems. Over a period of three years this Laboratory conducted a series of fitness tests under controlled conditions. Since methods and procedures were not changed during this period the data may be used for comparative purposes. Since study of fitness is as pertinent to conditions of peace as to those of war our experience is presented critically in order that future workers may be aware of the complexity and pitfalls of the problem and to suggest lines of future investigation which should clarify the concept of physical fitness. The analysis and discussion do not present a flattering picture of the tests but it is emphasized that they have served an extremely useful purpose during the emergency period. The less urgent times of peace permit a basic and comprehensive reconsideration of the whole problem of testing physical fitness.

CONCLUSIONS:

a. None of the tests studied is satisfactory for discriminating between degrees of individual fitness. This fault differs in kind and degree

among the tests. It arises from:

1. Failure to test chief components of fitness.
2. Inadequate scoring systems.
3. Abnormal distribution of performance achievement and/or score.
4. Lack of reproducibility.
5. Inability to control or measure motivation.
6. Inequality of stress on all persons.
7. Failure to consider physiologic cost or post-exercise conditions.
8. Presence of test components where readily acquired skills permit subjects to "beat the test".
9. Failure to consider environment or physique in scoring systems.

b. Several of the tests are satisfactory as gross measures of fitness and permit satisfactory comparison of groups.

c. A battery of fitness tests is a better measure than a single test.

d. Appraisal of fitness by good line and non-commissioned officers, familiar with their men, is as good or better than fitness tests in evaluating troops.

e. Performance tests, when competition is aroused, serve as incentives to improve fitness.

RECOMMENDATIONS:

a. That a far reaching program of basic investigation in physical fitness and reliable methods for testing it be included in the plan for post-war medical research relating to the army.

b. That the information contained in this report be made available to persons and agencies responsible for physiological research.

c. That until tests are further perfected they be considered as somewhat unreliable aids in evaluating individual fitness, not final determinants.

d. That the tests be considered fairly reliable means for discriminating between degrees of fitness in large groups of men.

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Approved Ray G Daggs
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Approved Frederick J Knoblauch
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A CRITIQUE OF PHYSICAL FITNESS TESTS

TABLE OF CONTENTS

I. A DEFINITION OF PHYSICAL FITNESS

Physical fitness is a term which has been applied to many phases of health and performance. Though its basic importance is widely recognized its definition is vague. To the physician it may signify absence of disease, to the athletic coach the perfection which comes from a program of training and to the employer it may mean satisfactory productivity in labor or industrial work. In terms of military tasks, fitness signifies something special and not interchangeable for the infantryman, the fighter pilot, and the submariner; fitness for attacking a tropical beachhead and an arctic pillbox may not be the same.

Physical fitness as the term is used in this report includes various attributes and is dependent upon the proper interplay of several functions. Physical fitness of whatever kind depends upon (1) a physique or anatomical structure permitting various activities, (2) a physiologic state compatible with carrying out the designated tasks, and (3) will-to-do which directs the person to do the job. In addition skill, a compound of native ability and training, influences performance. A measure of fitness should determine the resultant of these forces at a given time under set circumstances. Its utility hinges on applicability of the measurement to broader fields of performance than reside in the brief small scope of a fitness test.

From the military viewpoint, structural and functional components of physical fitness as well as motivation are requisites for effective performance. A test which would measure them separately would be useful since compensation, by masking a defect in one or another attribute, may reduce the likelihood of potential improvement. Strong motivation even with mediocre structure and physiologic state may yield better performance than poor motivation associated with excellent physique and functional state. Superior physiologic status may compensate for defects in structure. If the will-to-do is poor no test will assess physique and functional state. Therefore, present fitness tests can do no more than appraise the resultant of all factors contributing to fitness. They do not discriminate between or measure separate components. In specific terms physical fitness should include (1) capacity to endure for considerable periods of time multiple types of work on a high plane of energy expenditure, with (2) minimal disturbances of cardiorespiratory, muscular and other physiologic functions and (3) capacity for purposeful activity following work. A test should measure both accomplishment and cost. One must distinguish physical from medical fitness, structural from functional fitness, and soundness (endurance) from momentary fitness.

During the war the need for a simple but reliable test for fitness was urgent. Since no available test gave a satisfactory measure of performance a number of new ones were devised and have been used extensively. It is recognized that the tests have had manifold usefulness but they also have faults, some of which may be corrected by changing the scoring system or introducing new components or measures into the test. On the basis of the large body of data collected in various tests and surveys conducted by this laboratory, we have analyzed four widely used tests, pointed out defects and suggested methods of improving them.

II. COMPARISON OF TESTS

A. Sources of Data.

1. Fort Knox Studies: A total of 125 men was studied at Fort Knox during the winter and spring of 1943-1944 in order to compare their fitness ratings by the Harvard Fatigue Laboratory Step Test, the Navy Step Test, the Army Ground Forces Test, and the Army Air Force Test. All men were healthy enlisted volunteers between the ages of 18 and 33 years, with average age 21 years. They varied considerably in size and weight and recent physical training. The Navy and Harvard Step Tests were performed in an air-conditioned laboratory on a linoleum composition floor, the AGF and AAF tests were performed outdoors. All tests were run in the morning at least 2 hours after breakfast but the AGF Test was not done on the same day as the others. Rest periods of 45 to 75 minutes separated successive tests (AAF, Navy, and Harvard Step Test) while 15 to 20 minutes separated components of the AGF Test. Smoking was prohibited 15 to 20 minutes before a test. For further details see reference (1).

2. Colorado Studies: A battalion of 827 riflemen was used as subjects in an eight week study. These men, receiving final training for combat, were acting as subjects for the testing of field rations. The Harvard Step Test, the Army Air Force Test, and Army Ground Force Test were conducted at weekly intervals. The measurement of improving fitness under vigorous field activity in unusually well controlled conditions could thus be readily observed.

a. Subjects: Significant data are listed in Table 1.

TABLE 1

Characteristics	Range	Average
Age (years)	18-41	23.7
Weight (pounds)	111-215	152.8
Height (inches)	58-76	68.8
Length of Army Service (months)	6-149	21.9

b. Environment: The tests were conducted in the Pike National Forest in the Rocky Mountain area of central Colorado. It was an isolated area of rugged rock and timbered mountains, rolling hills and valleys and wide plains. The climate was temperate, with the maximum daily temperatures ranging from 72° to 92°F and minimum temperatures from 32° to 45°F. The altitude varied from 8700 to 9000 feet. (All subjects had spent several months at 6100 feet immediately prior to the test period.)

c. General Organization and Activity: The battalion was divided into six (6) companies. Training of all companies was uniform and each week's quantity of work was approximately equal to that of any other

week. Insofar as possible intensive infantry combat training, consisting mainly of practical field work was given; lectures were held to a minimum. Training included marches both night and day, combat firing, platoon and squad tactics, organization of the army, outpost problems, map reading and compass work, scouting and patrolling, tactical training of the individual, transition firing, bayonet training, field fortification, foxholes, grenade training, and night vision. Morale of the test subjects throughout the entire period was excellent. A spirit of competition between companies and between platoons within each company was maintained throughout and provided incentive in fitness testing.

d. Organization of Testing: A routine test day involved the following procedures: (a) weighing all men, (b) biochemical studies, (c) a clinical examination, (d) the Harvard Step Test, (e) the Army Air Force Test and (f) the Army Ground Forces Test which was carried out in the afternoon. The battery of fitness tests was given six (6) times. Test 1, in which the AGF Test was not included, was done at 6100 feet altitude; all others in the test area at 9000 feet. Test 2 was done the first full day in the test area. Test 3, done 7 days later, measured effects of acclimatization. The Step Test and the AAF Test were done in the morning, an hour separating the two. Half of the subjects did the Step Test first and half did the AAF Test first. The original sequence was followed by each subject in all subsequent tests. Order of sequence had no apparent effect on the scores. The AGF Test was begun an hour after lunch. Each component was done in the same sequence and interval rest sufficient only to catch the breath was allowed. The 4-mile march did not begin until 30 minutes after the zigzag was done. For further details see AMRL Report on Project No. 30, dated 22 November 1944 (2).

3. Pacific Study: The Harvard Step Test was done on selected subjects on Hawaii, Guadalcanal, Guam, Iwo Jima, and Luzon during the course of a nutrition survey.

The data were taken from samples of at least 50 men who had the characteristics listed in Table 2.

TABLE 2

Location	Age	Overseas	Percent White Troops	Height	Weight
Hawaii	29	23	80	68.7	158
Guadalcanal	28	20	82	68.8	155
Guam	26	21	72	67.9	154
Iwo Jima	26	17	82	69.1	150
Luzon	25	15	100	68.9	144

For further details see Armored Medical Research Laboratory report on Nutrition Survey in Pacific Ocean Areas dated 22 August 1945 (3).

B. Harvard Fatigue Laboratory Step Test: The Harvard Step Test attempts to measure fitness using two criteria (1) the duration up to the 5-minute limit of stepping up and down on a 2-inch platform and (2) the pulse rate for 30 seconds beginning 1 minute after cessation of this effort. To attain good scores the subject must have both good mechanical strength and ample cardiac reserve. Ideally, the measurement of pulse rate in recovery should be made after a standard task, and measurement of muscular strength should be independent. This has been attempted with only partial success in the Navy Step Test. In an attempt to make the procedure as simple as possible the Harvard Step Test combines these two components.

1. Colorado Data: Figure 1 shows the distribution of duration of exercise on the Step Test. On Test 2, 73% of men completed the full 5 minutes of effort and 96% of men on Test 6. In all 2500 tests conducted, 85% of men completed the full 5 minutes.

Distribution of the times achieved by men who failed to complete the full 5 minutes (Fig. 1) shows that very few men stopped between 4 and 5 minutes. The subjects were told how long they had been working and, presumably when within 1 minute of their goal, they expended the extra effort required to continue to the end.

An empirical relationship between performance time and pulse rate govern the scoring system as shown in Figure 2. This system gives 60 points for 5 minutes of effort and the remainder of the score is derived from the pulse rate response. The separation of 85% of soldiers into more and less fit men thus depends entirely on cardiovascular response to a standard severe task. The pulse rates of these men fall into a symmetrical distribution curve (see Fig. 3), which suggests that scoring for this group should be a linear function of the pulse rate rather than an exponential function as is now the case.

In this study only 15% of men failed to complete 5 minutes of stepping but in a group of less fit men this percentage would be much larger. When less than 5 minutes is completed the actual time of performance greatly influences the final score, and the pulse rate influences it to a lesser extent. In proportion to the mechanical weakness of the subject his score will be reduced. To demonstrate fitness in this group comparable to the group completing the full 5 minutes, there must be a definite correlation between mechanical and cardiovascular strength and it must be properly weighted in the scoring system. The evidence that this is not the case is as follows:

a. The distribution of scores for men completing 5 minutes follows a symmetrical curve (Fig. 4).* The addition of men failing to complete 5 minutes distorts this curve.

b. Satisfactory distribution curves of scores (Fig. 6) was obtained in the Colorado tests when 85% of men completed the full 5 minutes.

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* A slight distortion of the pulse rate distribution curve from which the score curve is derived is the result of the non-linear relationship between pulse rate and score previously noted. One obvious deficiency is the absence of any scores of 85 which is an artifact arising from the use of the scoring grid (Section VIII, Table 12).

When a smaller percent completed 5 minutes, the distribution curve was greatly distorted. This can be seen in the curve marked "Hawaii and Guadalcanal" of Figure 6.

c. The heart rate of men completing 5 minutes on the Step Test correlates very poorly with components of the AAF and AGF Tests in which mechanical strength is the chief requirement for a good score. An example is shown in Figure 5.

d. The scores of men who do not complete the full 5 minutes vary much more than the scores of those who do complete the required time. Although this may result from improper motivation or other factors, it introduces an irregularity in the test, particularly in the low score range.

e. Scores made by men completing the full 5 minutes correlate well with AAF Test scores, while the Step Test scores of those failing to complete 5 minutes correlate very poorly.

f. Vagal bradycardia may produce a spurious score not really related to fitness under certain conditions (4).

2. Pacific Data: Results of the Harvard Step Test in the Pacific Nutrition Survey are presented in condensed form in Figure 6. Since the distribution curves for Hawaii and Guadalcanal were nearly alike they were combined, as were those for Guam and Iwo Jima. The data from the Pacific have been compared with scores from the first and last test in the Colorado Ration Trials. The distribution curves fall into three distinct groups with low, medium and high scores. The low scores made by subjects on Hawaii and Guadalcanal may be explained only in part by the higher average age and greater weight of the subjects, both of which are associated with lower scores. Though the differences were not large, the environmental factor of heat load was greatest on Guadalcanal and least on Hawaii. The score indicates a low state of fitness consistent with sedentary work and lack of arduous exercise. The distribution curve for the combined data from Guam and Iwo Jima is quite similar to the curve for the first test in the Colorado infantry battalion, although the mean score for the latter is 2 points lower. This is interpreted as indicating a very similar state of fitness in the two groups--a state of average fitness in garrison troops without active training. The highest scores were made by the Colorado test subjects at the end of 8 weeks' intensive training in the field. Distribution of scores from the infantry division in the lines on Luzon is strikingly similar. Age and weight were nearly alike in these groups. It is concluded that the distribution and mean values for Step Test scores of these two groups of subjects indicate a high level of fitness consistent with either effective training or vigorous combat activity and associated with high morale.

Distribution curves in Figure 6 fall into 3 distinct ranges, a poor, an intermediate, and a good. These curves agreed with the observer's impression of the actual state of the men. The test, therefore, has utility in separation of groups, regardless of its defects in evaluating fitness in a single person.

The studies using one simple fitness test demonstrate its utility in field studies when lack of personnel, apparatus and time require a simple rapid test.

Practically, the Harvard Step Test is very easy to carry out, requiring little apparatus. One observer can process 10 or more men an hour. It can be done in the field where more complex tests would be impossible. Subjects dislike the test because of the strain on the leg muscles which often produces soreness, and the dyspnea and fatigue which are out of proportion to the energy used. These objections indicate that the test really taxes the subject.

From these observations it appears that the Harvard Step Test uses two distinct elements of physical fitness--cardiovascular strength and mechanical strength--in a combination which does not permit strict comparison of men within a test group except the very fit men who complete 5 minutes of stepping. Despite these limitations the test is a useful one and serves to give an approximate overall evaluation of the fitness of a group of men.

C. Navy Step Test: The inclusion of a distinct cardiovascular part and endurance part in the Navy Step Test is an attempt to include the two chief components of fitness. The distribution of scores skews markedly to the right and is very asymmetrical (5). Because the score is very largely determined by the endurance component, the test loses much of its potential value. In addition, it requires a preceding period of rest, and several observations of pulse rate, rendering its administration to large groups very difficult. Karpovitch has made an analysis of the AAF, Harvard and Navy Tests and found that the test-retest reliability of the Navy Test gave an R value of only + 0.48. Studies in this laboratory (1) pointed to the same conclusions independently. Therefore the Navy Test was not included in the battery of tests carried out in the Colorado Ration Trials. Revision of the scoring system would improve the usefulness of the test.

D. The AAF Fitness Test: The 3 components of the AAF Test are a 300-yard shuttle run, sit-ups, and pull-ups. The AAF score is the average of the scores for each component.

1. Three Hundred-Yard Shuttle Run: In the shuttle run the subject must run five 60-yard laps, making a 180° turn at the end of each except the last. The score is based on the time required to traverse the entire course, and a good score requires both sprinting speed and agility in making the turns. The very poor correlations of this test with the Harvard Step Test suggest that the duration of the run is too short for cardiovascular function to be a limiting factor.

The score of the Colorado group on the run was considerably below the "good" rating. Among the reasons for poor performance were: (a) The sandy terrain which was poor for running: (b) regulation army combat boots were worn after Test 1.

The total AAF scores were relatively much lower than the Harvard Step Test or AGF scores where no such hindrances existed, or affected only a fraction of the test components.

Figure 7 shows the distribution of running time in 2 tests in the Colorado study. Definite improvement is noted. Bunching at the low time (high score) portion of the scale appears with improving fitness. This tendency is presumably the result of some factor, perhaps body configuration, which imposes a limit on performance little effected by improving general fitness. The scoring system of the test recognizes this tendency. A given decrement in running time receives more score credit when made at the low time end of the score than the same decrement made in the middle or high end of the scale (Fig. 8). This "correction" is in the proper direction but not sufficient to give a symmetrical distribution of scores.

2. Sit-Ups: In this test component, sit-ups must be performed in a prescribed manner, except that some variation in rate is allowed. The score increases with the number of sit-ups up to 114. Beyond 114 sit-ups no further score accrues. The test places a heavy strain on the muscles of the trunk and pelvis and muscle fatigue is the limiting factor in the number of sit-ups that can be performed.

The distribution of the number of sit-ups on Tests 2 and 6 may be seen in Figure 9. Two features of the curve are of interest. First, a group of men was able to complete the full 114 sit-ups necessary to make a perfect score. In Test 2, this was 6% of the total number of men; in Test 6, 20% of all men. In Test 2, more than 90% of men who completed 114 sit-ups were in a single test company. It is possible that this company used a technique which spared them muscular effort and permitted them to attain perfect scores. However, in Test 6, the men who performed 114 sit-ups were evenly distributed throughout all test groups. No break in the rules for performance of the test could be detected to account for this exceptional performance. The second feature of interest is the extension of the distribution curve toward the high number of performances, in contrast to that of the shuttle run which shows bunching as peak performance is approached. In the shuttle runs it was hypothesized that the mechanical structure of the body imposed a limit on performance which checked increase in score though fitness in general was still improving. In the sit-ups the opposite effect, i.e. improvement in score without corresponding increase in fitness, may arise from learning a knack which enables a man to spare himself muscular effort. Again, score does not accurately reflect general physical fitness.

It could be argued that the ability to learn a knack is in itself a measure of physical fitness, but this does not seem to be the case. The AAF scores of men performing 114 sit-ups are contrasted with the men performing between 60-90 push-ups (Table 3). Whereas men accomplishing 114 sit-ups scored very much higher on the AAF Test, they did not score significantly higher on other tests.

TABLE 3

	SCORE		
	AAF	AGF	Harvard
"114" Group	62.3	86.8	81.1
"60-90" Group	48.7	83.5	79.7

The scoring system for the sit-ups gives more credit for increments in performance at the low end of the scale than at the high end. (Fig. 10). This partly offsets the skewing of the distribution curve of performance. The correction is not sufficient to give a symmetrical distribution of scores and it does not affect the men attaining perfect scores.

3. Pull-Ups: The pull-up component of the AAF Test is a measure of the muscular strength of the arm and shoulder muscle group. The test is of short duration and the limiting factor in performance is muscular fatigue.

Distribution curves of performance in Test 2 and Test 6 show symmetrical curves with a symmetrical shift of the entire curve with improving performance (Fig. 11). The score should be in linear proportion to the performance and this is almost the case in the official scoring system. At the extremes of performance there is a slight departure from linearity which has only slight effect on the classification of a small percentage of men.

The division of men into thirds of least, average, and most fit depends on a mean difference of slightly more than 4 chin-ups. However, in the series of tests performed over 57 days the men increased only 2 chin-ups, from 7 to 9. This suggests that only marked gross changes in fitness would be detected by this component of the test.

4. AAF Test as a Unit: In each component of the AAF Test some deficiency has been noted. Each deficiency reduces the reliability of the result for a certain percentage of the men. In the case of sit-ups this percentage may be quite large and will have a considerable effect on the final AAF score.

The distribution of total scores on Test 2 and Test 6 of the Colorado study are shown in Figure 12. As would be anticipated from the distribution curves of the separate test components, this curve is also asymmetrical. There is a pronounced shift toward higher scores from Test 2 to Test 6; however, the form of the curve remains about the same. The improvement in fitness in the AAF Test for the group of men as a whole correlates well with the improvement noted by the Harvard Step Test and the AGF Test.

E. <u>AGF Fitness Test</u>: The 6 components of the AGF Test and their percent contribution to the final AGF score are listed in Table 4.

TABLE 4

Name of Test	Character of Test	Contribution to Final Score
4-mile march	Subject carries pack & rifle*	30%
300-yard run	Two 150-yard laps with 180° turn	20%
75-yard pig-a-back-run	Subject carries man of equal weight	20%
Zigzag run	Combines creeping, crawling, broad jumping	10%
Push-ups	Standard calisthenic exercise	10%
Burpees	Standard calisthenic exercise	10%

* Standardized in the Colorado Test to weigh 20-30 pounds.

1. Four-Mile March: In this component, the scoring system penalizes the subject for straggling at each mile marker and again for lateness at the finish. If the subject is on time at each mile and finishes in 50 minutes he receives a perfect score.

Performance in the 4-mile march is shown in Figure 13. In Test 2, 40% of men finished on time and Test 6, virtually 100% of men. It is obvious, then, that for the degree of fitness reached by Test 6 the scoring system will not discriminate at all between the more and less fit men of the groups.

2. Three Hundred-Yard Run, Pig-a-back Run, and Zigzag Run: The distribution curves of performance in the running components of the AGF Test show a tendency toward bunching of men as fitness improves (Figs. 14, 15 and 16). As in the AAF shuttle run, this tendency does not necessarily indicate that fitness is reaching a maximum, but may only indicate that some mechanical factor such as body construction is limiting running speeds. No correction in the AGF scoring system has been attempted for this trend.

3. Push-Ups: The distribution curve of push-ups has a curious form with improving fitness (Fig. 17). This tendency is noted in Tests 4, 5 and 6. It is the result of a maximum score having been arbitrarily placed at 34 push-ups. The men made great efforts to reach 34 but not to continue beyond that figure, as they would receive no further credit. As in the Harvard Step Test, there is a dip in the distribution curve in the region just short of a perfect score which indicates that men who near the mark probably make an extra effort while those who feel they cannot reach perfection quit before exhaustion. In the zigzag runs and pig-a-back runs where most men were finally making perfect scores they had no reliable guide as to their time and did not slow down.

4. Burpees: The distribution of burpees performed (Fig. 18) is a symmetrical curve and shifts symmetrically with improving performance. As in the AAF chin-up test, however, a small difference in the number of performances has a profound effect on the fitness classification.

5. AGF Test as a Unit: The AGF Test has certain features which should make it the most accurate index of fitness for army use. The first is the fact that it employs 6 components. The lack of correlations found in this study between test components indicate that each component measures a different aspect of fitness or that each is highly unreliable. In either instance greater reliability will be achieved by increasing the number of components. The test components are very similar or identical in many cases to the actual activity of the infantry soldier in the field or combat. In other words, a large part of the AGF Test is a direct measurement of practical military performance.

The use of a large number of components has the disadvantage of making the test difficult to administer. About 15 men are required for the rapid testing of any group larger than 25 subjects. Organizing and measuring the test areas is time and labor consuming.

A very bad defect of the AGF Test is the scoring system. The dotted vertical lines on the distribution curves of performance show the levels of performance necessary for a perfect score. Obviously in many components performance is possible beyond the line of maximum score and no additional credit is given by the scoring system. This effect is seen in the distribution of total AGF scores plotted for Test 2 and for Test 6 (Fig. 19). Satisfactory distribution occurs only for the lower half of scores on Test 2. In Test 6, bunching of the group has occurred to a great extent because a large fraction of men have reached perfect scores in several components. Clearly the fitness of the group as a whole will not be correctly indicated and estimation of individual fitness within the group will be very unsatisfactory. The scoring system should include the highest degree of performance for which data are available and it should be proportional to the performance distribution curve in a manner to give a symmetrical distribution of scores.* (See AAF Test.)

F. Correlation Among Tests and Test Components:

1. Correlations of Tests: Correlation was poor with the Harvard Step Test scores and both the AAF and AGF Test scores. Correlation was fair between the AAF and AGF Test scores (Table 5).

TABLE 5

Tests	Correlation
Harvard vs AAF	.24
Harvard vs AGF	.26
AGF vs AAF	.68

2. Scatter Diagrams were made to establish correlation between certain test components and groups of test components. To avoid errors due to artifacts of the scoring systems, the scatter diagrams were either plots of actual performance, or new scoring systems were used which were directly proportional to performance. Correlation coefficients were not calculated. The diagrams and estimates of correlation are listed in Table 6.

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* This correlation cannot be undertaken from this study because the actual performance times on the 4-mile march were not recorded.

TABLE 6

Test Components	Estimation of Correlation
AGF Burpee vs AGF Push-up	Very poor
AGF 300-Yard vs AGF Pig-a-back	Very poor
AGF Push-ups vs AAF Chin-ups	Very poor
AGF Burpee vs AGF Zigzag	Very poor
AGF 300-Yard Run vs AAF 300-Yard Shuttle Run	Poor
AAF Shuttle Run vs Harvard Step Test	Very poor

Test Group	Estimation of Correlation
AGF Test without march vs AAF Test	Fair
AGF Burpee + Zigzag + Push-ups vs AGF Pig-a-back + 300-Yard Run	Very poor
AAF Test vs Harvard + AGF Tests	Fair

3. Improvement in Fitness: The mean scores made on each test have been plotted for successive days (Fig. 20). Although the correlation between individual tests is not good, the degree of mean improvement in fitness indicated by each test is similar. The rate of improvement in fitness appears to lessen in the last days. This may be an artifact of the scoring system arising from the use of maximum scores in many test components. (See discussion of AGF Test.)

G. Caloric Expenditure in Different Parts of the Fitness Tests:

A calculation of the expenditure of Calories on the 10 different exercises of the 3 fitness tests was carried out on selected subjects. The standard open-circuit Douglas bag technic and Haldane analysis were used in the collection of data. These data, calculated as additional cost over and above the average expenditure for very light activity (100 Cals/hr), are given for the usual performance in total work done:

	Calories	Time of Duration or Number of Times Exercise is Completed
Step Test	61	5 minutes
Sit-ups	35	100 sit-ups
Chin-ups	7	10 chin-ups
300-Yard Shuttle Run	21	60-70 seconds
Push-ups	6	20 push-ups
300-Yard Run	22	60-70 seconds
Burpees	10	20 seconds
Pig-a-back	12	20 seconds
Zigzag	14	30 seconds
4-mile Road March, Pack and Equipment (30 pounds)	448	50 minutes
TOTAL	636	

III. ENVIRONMENTAL INFLUENCES ON PERFORMANCE

A. External Factors: Factors in the external environment influence performance in two ways: (1) they may actually alter fitness as in work at high altitudes or in the heat, especially before acclimatization has taken place; (2) they may interfere with carrying out a set task as, for example, running on a muddy or sandy track. Such effects are independent of the state of fitness as determined under a standard environment without extrinsic interference. Nevertheless, influences of this class have often been disregarded in setting up specifications for performance tests, and no scoring procedure has been established which allows for proper weighting of environmental factors of several types. Any test conducted out-of-doors may be disturbed by rain and wind; is influenced by terrain, by firmness of ground, by mud or dust, by stability of equipment or apparatus and sometimes by glare and sunshine. Constricting, ill-fitting or loose clothes and heavy or poorly adjusted shoes interfere notoriously with running, whereas an obstacle course may be negotiated more expeditiously with protective clothing. A general criticism of fitness tests is their lack of regard for the influence of the external environment upon performance. This has prevented exact comparison of tests in groups when environmental influences may have changed.

B. Intrinsic Factors:

1. Physique: Studies of physical fitness have not advanced to the stage where a separation of the various components of performance may be analyzed. One of the important fields for future investigation is the role of body structure in determining performance. It is well known that different body types may be associated with superior performance in different fields. Thus, the good sprinter or distance runner is apt to have a slim wiry build whereas a wrestler is usually heavier and more muscular. Fitness for one task does not imply fitness for another. Obesity is a concomitant of poor condition but height-weight tables do not differentiate mere fatness from the sounder heaviness which may be associated with excellent physical fitness. Behnke et al (6, 7) have shown that specific gravity is a better criterion than poundage since it separates the obese from the muscular. Height and limb length influence performance for purely mechanical reasons. Anthropologic type may affect fitness in a specific fashion, although if an influence other than the suspected role of physique exists it has not been measured. One may believe that racial characteristics, separate from physique, may affect muscular efficiency or other aspects of performance in view of the work done by coolies and groups of laborers. But here, too, the possible effects of training and practice remain to be evaluated against the scarcely measured forces of survival of the fittest in its Darwinian sense. Performance is in part influenced by the course of growth and aging but whether this is mostly a phenomenon of structural change, of biochemical development or of skill and practice is not known. Similarly, the decay of performance with aging is not resolved into its component mechanisms. If such factors are not evaluated a fitness test may measure structure much or little depending on the type of test.

2. Physiologic State: The physiologic and biochemical determinants of fitness are governed by external as well as inherent forces only a

few of which are understood, Proper nutrition is a basic requirement of performance. Many types of nutritional aberrations cause a deterioration of performance. These run the gamut from a bone change resulting from chronic calcium depletion to the effect of acute caloric starvation. The effect of deficiencies in B-complex vitamins upon performance has been studied only recently for a few factors. Water and electrolyte equilibria must be maintained in proper balance for the best fitness. The effect of drugs such as alcohol and analeptics must be evaluated. Muscular efficiency and oxidation processes have received extensive study and have had a marked influence in devising tests to appraise fitness.

C. Miscellaneous: Many additional influences have great importance in performance. Of these the chief is the intangible motivation, morale or will-to-do. It dominates performance and is therefore an integral part of fitness. Without it no test of fitness gives a measure of more than an unknown fraction of potential performance. Additional factors such as time of day, elapsed time since meals, quantity and type of food eaten, sequence of tests if several are carried out in rapid succession, rest, sleep and fatigue all add their effects to the underlying attributes which govern performance. The role of innate coordination, learning to accomplish muscular work with least effort and tricks which reduce energy expenditure in a set task, must be evaluated against the real improvement in fitness which comes from the repeated practice which constitutes training. When environmental conditions such as heat and high altitude are encountered improvement from acclimatization must be separated from genuine enhancement of fitness.

Unless all factors are evaluated and separated insofar as possible, any test of fitness may give spurious answers because of the multitude of environmental conditions which affect performance even when fitness itself remains static. Every possible control must be used to regulate the conditions of a test in order that a score will have significance in meaningful terms. Whenever external influences cannot be eliminated they must be measured and recorded in order to appraise their effect upon the results of any test.

IV. SUBJECTIVE AND OBJECTIVE MEASURES OF FITNESS

The final standard against which physical fitness tests must be judged is actual performance. In order to compare a test score with performance, the latter must have some measure in quantitative units by which a score may be validated or invalidated. In the absence of preselection, job analysis or other objective methods of assignment of personnel on the basis of capacity, the infantry soldier is rated by his line and noncommissioned officers. His duties in the field are allotted on the basis of his superior's judgment. Although this is no infallible criterion it has worked out surprisingly well in the hands of capable leaders. It is the method by which the infantryman is given designated tasks. It is of considerable interest to compare the sum of scores on the 3 fitness tests at Colorado with arbitrary ratings of poor, fair, and good given the subjects on the day of testing by their line and noncommissioned officers. Figure 21 illustrates the results of plotting the sum of the scores on the 3 fitness tests against the percentage of ratings of good, fair, and poor in class intervals of 10. Each of the three ratings forms a clearly defined curve with a location which agrees with what would be expected. Though the ratings are arbitrary and varied somewhat with different officers, the pooled data show a very striking agreement between scores and ratings. A similar procedure carried out by the observers gave no significant correlation between ratings and scores, an indication that the exercise of command and living with their men probably enabled the line officers to form a more just estimate of fitness than mere association did in the case of the observers who had no experience in command.

V. RELATIONSHIP OF FITNESS TO OTHER FACTORS

A. Relationship Between Clinical Signs of Nutritional Significance and Scores on Fitness Tests

Two criteria in evaluating health are clinical signs of malnutrition and performance in tests of physical fitness. Little information has existed upon correlation between signs of nutritional deficiency and performance among either the grossly malnourished or well nourished. In the Colorado Test clinical examination and physical fitness tests were given 4 times on the same day at 2 or 3-week intervals to 6 infantry companies. This afforded an opportunity to see whether performance on fitness tests and clinical signs were related.

Data on 4 complete sets of clinical examinations and fitness tests were assembled on a total of 441 men (1764 examinations and tests). Physical fitness scores for each company-date group were separated according to the presence or absence of each abnormality. The mean differences between normal and abnormal groups were calculated for each fitness test. The 24 "within company-date" mean differences were averaged by weighting each of the harmonic mean of the number of men with the number without the abnormality in that "company-date" subclass. Finally the weighted average "within company-date" differences between normal and abnormal men were tested for statistical significance using the standard deviations.

Of 72 possible correlations, 14 were found to be of statistical significance; of these, 12 were in favor of the normal men. Four considerations render these differences of no practical importance: (1) the differences were all small, rarely amounting to a difference of 5 points whereas the experimental error of the fitness tests is actually larger than this; (2) variations among the clinical observers could easily have accounted for many differences between the so called "normal" and "abnormal" subject; (3) the number with positive physical findings was much smaller than the number without and, in fact, hardly significant; (4) many physical signs were isolated phenomena and not related to deficiency disease syndromes. It appears,therefore, that the small but statistically significant differences between certain clinical abnormalities and performance scores are actually of no practical importance. Men rated lowest clinically made practically as good scores as those rated highest; men with best performance and practically as high an incidence of clinical abnormalities as those with worst performance. It appears that, in a normal group, small aberrations in clinical signs are inconsequential in terms of fitness scores.

B. Relationship Between Biochemical Levels in Blood and Urine, and Performance on Physical Fitness Tests

One of the requisites for good performance is a proper function of the physiologic and biochemical systems which govern muscular and cardiovascular fitness. Little is known of the relationship between performance and the vitamin content of blood and urine in a large group of healthy young men. Biochemical determination on hemoglobin, serum protein, serum and urine chloride, fasting and load ascorbic acid, thiamine, riboflavin and F_2 factor in the urine, were made on the same day as the fitness tests. Data for all

men with 4 complete sets of observations were calculated for "within company-date" correlations between scores on each fitness test and the 12 chemical determinations. Of the 36 correlations coefficients only 5 were significant, three of these being negative, and all very small. The positive correlations between AAF scores and fasting riboflavin and load ascorbic acid are not considered to have any real meaning. It is concluded that in reasonably healthy and fit young men there is no important correlation between vitamin levels and scores on fitness tests.

C. Relationship of Age, Height, Weight for Height and Recent Caloric Intake to Physical Fitness

If fitness tests are of help in evaluating fitness and nutritional status it is essential to know how performance is related to age, height, weight, and recent food intake. Data on age, height, fasting weight, 3 fitness test scores and 10 individual events were available from the ration test material. For 2 of the test periods caloric intake for the preceding 3 weeks was recorded for each subject. For all men with complete data "within company" correlations were calculated and tested for significance for (1) age and fitness test scores, (2) weight and fitness test scores, (3) weight in excess of average for corresponding height and fitness test scores, and (4) caloric consumption for the preceding 3 weeks and fitness test scores.

1. Age: Age was negatively correlated with scores on all 3 tests at each of the 4 periods studied (Tables 7 and 8). In separate events this correlation occurred with AAF Test sit-ups and run, but not pull-ups. In the AGF Test the correlation occurred in the burpee and the shuttle, pig-a-back, and zigzag runs. The regression of scores on age was not linear. There was a tendency for scores to be about the same for ages up through the middle twenties and then to drop off fairly sharply though not very much. The test scores for different age groups are given in Table 8. In the AAF Test on the first day, a rather sharp decline in scores began after the age of 24; this break came after the age of 27 in the last test. In the first AGF Test, the gradual decline began after the age of 22; in the last test, it began only after the age of 29 and was much less marked. In the first Step Test, the decline came after 26; in the last test, a real decline came only after the age of 32. Insofar as the improvement in score indicates enhanced fitness, it may be said that the effect of age is not noticed in trained men as early as in untrained men. Improvement was nearly the same for all ages in the AAF Test, but the older men (with lower scores) improved more than the younger men in the other tests.

2. Height: Similar correlations were carried out between height and scores on fitness tests (Tables 7 and 9). Height was not correlated with Step Test scores, but was with AAF scores and on the initial test only with AGF scores. Previous studies by Pace (5) indicated a lack of correlation between Step Test scores and height for the Navy Test done on an 18-inch platform. Data from the Harvard Fatigue Laboratory indicate that only extremes of height affected scores by handicapping the very short and facilitating the very tall. In the events of the AAF Test, taller men tended to do more sit-ups and to make faster time on the runs but did fewer pull-ups. The well-known handicap of the short-legged man, and the mechanical dis-

TABLE 7

SIMPLE CORRELATIONS OF PHYSICAL FITNESS PERFORMANCES WITH AGE, HEIGHT, WEIGHT IN EXCESS OF AVERAGE, AND PRECEDING CALORIE INTAKE

Variables	Day of Test	Physical Fitness Test										
		Harvard Score	Sit-up	Pull-Up	Run	AAF Score	Push-Up	Run	Burpee	Pig-a-Back	Zigzag	AGF Score
Age	D	-.18*	-.17*	-.06	.20*	-.24*	-.07	.17*	.01	.19*	.14	-.20*
	D + 21	-.16*	-.16*	-.09	.13	-.22*	-.10	.18*	-.20*	.21*	.10	-.16*
	D + 35	-.19*	-.17*	-.03	.15	-.20*	-.07	.17*	-.12	.13	.10	-.12
	D + 56	-.13	-.14	.01	.16*	-.16*	-.11	.16*	-.11	.23*	0	-.18*
Height	D	.01	.21*	-.28*	-.10	.08	-.31*	-.18*	-.01	-.06	-.05	.17*
	D + 21	.03	.24*	-.23*	-.13	.13	-.22*	-.13*	-.10	-.01	.02	.09
	D + 35	.06	.25*	-.23*	-.15*	.15*	-.24*	-.19*	-.04	-.06	.09	.08
	D + 56	-.01	.23*	-.23*	-.07	.11	-.22*	-.07	0	-.08	.03	-.05
Wt in Excess of Av for Ht	D	-.30*	-.07	-.36*	.12	-.20*	.08	.04	.02	-.09	-.12	-.01
	D + 21	-.14	-.05	-.24*	.01	-.21*	-.04	-.01	-.01	-.07	-.02	.07
	D + 35	-.12	-.06	-.23*	.01	-.13	.05	.04	.01	-.10	.03	.02
	D + 56	.01	-.02	-.16*	.05	.05	-.01	.11	0	-.01	.10	-.09
Cal Intake D to D+20	D + 21	.11	.07	.09	-.20*	.19*	.11	-.23*	.13	-.16*	-.06	.28*
Cal Intake D to D+55	D + 56	.10	0	.06	-.11	.06	.05	-.20*	.01	-.07	-.18*	.12

* Statistically significant

TABLE 8

PHYSICAL FITNESS SCORES MADE BY DIFFERENT AGE GROUPS

Age Group	Test											
	Harvard				AAF				AGF			
	D	D+21	D+35	D+56	D	D+21	D+35	D+56	D	D+21	D+35	D+56
19-20	66	80	79	84	39	46	47	50	76	86	86	89
21-22	66	78	79	84	38	43	46	49	76	85	86	90
23-24	70	78	84	85	39	42	46	49	76	86	88	89
25-26	66	72	78	82	35	43	45	48	72	85	86	89
27-28	66	75	78	80	37	42	45	47	74	85	86	89
29-30	61	75	76	84	34	41	44	47	72	84	84	87
31-up	57	72	71	77	33	38	41	46	70	83	84	86

TABLE 9

PHYSICAL FITNESS SCORES MADE BY DIFFERENT HEIGHT GROUPS

Height Group	Test											
	Harvard				AAF				AGF			
	D	D+21	D+35	D+56	D	D+21	D+35	D+56	D	D+21	D+35	D+56
61-64	71	79	81	91	37	41	43	48	71	83	83	91
65	64	72	76	81	37	42	46	50	72	85	89	90
66	66	76	75	82	37	43	45	48	73	86	87	89
67	65	79	80	84	37	42	45	47	75	85	85	89
68	62	73	76	79	36	41	44	47	72	84	85	88
69	67	73	80	86	35	40	41	45	74	84	85	88
70	63	81	83	85	37	44	48	52	76	86	85	89
71	63	77	76	80	40	45	49	51	79	88	88	89
72	68	78	80	83	39	46	51	52	77	87	88	90
73 & up	71	76	80	83	39	45	48	50	78	86	87	88

advantage in height of lift in pull-ups seem satisfactory as an explanation. A priori, one might expect the tall men to encounter more difficulties in the sit-ups owing to the lower arc through which the upper half of the body must bend, but this did not prove to be the case. In the AGF Test, also, the taller men tended to make better times on the shuttle run and more tended to finish the 4-mile march on time. They did fewer push-ups. It appears that mechanical reasons probably account for the differences in performance between tall men and those of average height, although the sit-ups may be an exception.

3. Weight for Height: In each height range, the heavier men tended to make lower Step Test scores, do fewer pull-ups and make lower AAF Test scores. These differences were more pronounced on earlier tests and in some cases had disappeared by the last test. Except for a poorer score on the zig-zag on the first test, there was no correlation between AGF Test scores or events and excess weight for height. Improvement in Step Test and AAF Test scores was directly correlated with loss of body weight.

4. Calorie Consumption: There was a highly significant positive correlation between calorie intake for the first 3 weeks of the test and AAF and AGF Test scores at the end of the period. (Table 10). Men who ate more tended to make faster times on the pig-a-back and shuttle runs, do more burpees and more of them finished the 4-mile march on time. These differences were not so evident by the last test where there had been a general improvement in performance.

TABLE 10

PHYSICAL FITNESS SCORES MADE BY MEN CONSUMING DIFFERENT NUMBERS OF CALORIES DURING THREE WEEKS PRECEDING THE TESTS

Daily Calorie Consumption	Average Physical Fitness Test Scores		
	Step Test	AAF Test	AGF Test
1450 - 2319	75	41	82
2320 - 2449	64	38	80
2450 - 2589	78	38	82
2590 - 2679	76	43	84
3000 - 3139	74	42	85
3140 - 3269	77	42	85
3270 - 3409	80	44	85
3410 - 3539	78	43	86
3540 - 3679	78	42	84
3680 - 3819	77	45	89
3820 - 3949	75	45	90
3950 - 4449	86	48	93

VI. HISTORICAL REVIEW

The fundamental importance of performance is epitomized in evolutionary terms as "survival of the fittest". This was recognized long before subjective estimates or objective measures of fitness were ever systematized. Civilizations based on the work output of slaves or the performance of soldiers understood the practical aspects of physical fitness. Although attempts at precise measurement are modern, thousands of years ago Chinese folk medicine employed a breath holding and pulse counting test for longevity and similar methods are still employed. The Athenian stress on physique and the Spartan stress on ruggedness and endurance emphasized two aspects of fitness which enjoyed a place in the state religions of antiquity. Nevertheless, it has been only in recent times that an objective approach to the problem has been provided by the development of physiology and allied sciences.

Fitness tests have been classified as performance and non-performance (8) and more elaborately into (1) anthropometric, (2) physical performance, (3) respiratory-circulatory, (4) cardiovascular and (5) cardiovascular-physical performance tests (6). Using the latter classification some of the better known tests are considered in this section.

A. Anthropometric: This method of evaluating fitness is based chiefly on stature, sitting height and chest measurements and ratios of weight and height. Although such information has been used to supplement other data, the Army Air Forces (9) have indicated that anthropometry may be used extensively in the selection of pilots. Heath, et al. (10) consider the masculine component in the selection of officer candidates and show its relation to physical fitness as judged by the Harvard Step Test. Further evaluation is needed before reliance is placed too exclusively upon morphology alone.

B. Physical Performance: The first tests to be used as a gauge of general fitness were based chiefly on strength. Weight lifting and dynamometers for testing strength of various muscle groups are still used and are of limited value. Calisthenic exercises have been used extensively. They include the Army Air Forces Test and the Army Ground Forces Test which are described in detail later. The Army Air Forces Test (11, 12) was devised in an attempt to define and measure elements of fitness required for duty with the Air Forces. Seven elements were considered important and a battery of 15 tests was devised to measure them. These were first reduced to 7 and later to 3 tests which had a correlation coefficient of 0.90 with the original 15 tests. In addition to the Ground Forces Test, others used by the Army include obstacle course runs with score based on time, and an endurance hike with full field pack with score based on the time required to complete the hike.

Another test to measure motor fitness is the Illinois Motor Fitness Screen Test (8), composed of 14 components which attempt to measure 6 elements of motor fitness: balance, flexibility, agility, strength, power, and endurance. Additional requirements include swimming ability and rating of physique.

C. Respiratory-Circulatory: During the last war Flack (13) was interested in determining fitness and fatigue in men of the Royal Air Force. He used 6 tests, 5 being based on respiratory function. The 4 most used were: breath-holding test, vital capacity, expiratory force test and persistence test in which the mercury in a manometer was kept at half the height obtained during the expiratory force test for as many seconds as possible without breathing. The behavior of the pulse during this period was noted. The Flack-Woodham Index of fitness of young and adolescent boys was a development directed toward an estimate of physical fitness.

$$\text{F-W Index of Fitness} = \frac{Pr \times Per \times Br}{100 \times \left(\frac{\text{Age in Years}}{4}\right) 1.807}$$

where Pr = Max. expiratory force in mm. of Hg.

Per = Time in seconds of breath hold in the persistence test.

Br = The time in seconds of the breath holding test.

L. D. Cripps (14) found that variations of the respiratory test even in a highly selected group were so great that fixing a normal standard was impossible.

In 1935, McCurdy and Larson (15) introduced a test in which observations are made on diastolic pressure (sitting), breath holding 20 seconds after a stair climbing exercise, difference between standing pulse and pulse rate 2 minutes after exercise, standing pulse rate and vital capacity. The amount of exercise is determined from a table of age and weight. Scoring is calculated from these tables.

D. Cardiovascular: In 1904 Crampton presented his "Blood Ptosis Test". The scoring of the test was revised in 1913 (16) and 1920. The test is based on the concept that with poor physical condition there is a lack of vasomotor control and vascular tonicity with resulting blood ptosis and a drop in systolic pressure. Good physical condition causes a compensation and the blood pressure rises. Pulse rates rise in the unfit and remain the same or rise only slightly in the fit. The two elements considered are "an increase in systolic blood pressure which connotes efficiency and an increase in pulse rate which connotes deficiency". Original ranges were found to be +10 to -10 for changes of systolic blood pressure, and 0 to +44 for pulse increase. "Upon a statistical balancing of these two series of frequencies, the assigning equal percentages to equal ranges, a scale was constructed for evaluation". In 1920 this was extended (17) to give values for increases in heart rate as high as 80/min. and systolic blood pressure variations of 50 mm. Hg.

Meylan, (18) in 1913, judged efficiency by the following: (a) weight, color of skin, and general appearance such as firm vigorous muscles, (b) pulse rate in the horizontal and vertical positions, (c) systolic blood pressure in the horizontal and vertical positions, and (d) heart reaction after hopping 100 feet.

Foster, (19) in 1914, introduced a test involving heart rate in the quiet standing position, immediately after running in a fixed place for exactly 15 seconds at a rate of 180 steps per minute, and 45 seconds after cessation of the exercise.

In 1917, Barringer (20) introduced a test based on the "delay rise" of systolic blood pressure following exercise. He believed that a delayed rise represented an overtaxing of the reserve power of the heart and was associated with a prolonged fall toward the normal resting level. Increasing amounts of work were given the subject at widely separated intervals until a "delayed rise" was elicited.

Sewall (21) later showed that a weakened patient may not have a systolic drop as indicated by Crampton, but a rise of diastolic pressure and a small pulse pressure. He employed these as measures of fitness.

Schneider, (22, 23) in 1920 and 1923, introduced a test which has been used extensively to estimate fitness of pilots. He considered that previous cardiovascular tests were not comprehensive enough. He developed a test which weighs data from 6 sets of observations: pulse rate during recumbency, pulse rate increase on standing, exercise pulse rate, and decline in pulse rate following exercise, resting systolic blood pressure, and systolic blood pressure upon standing.

Turner, (24) in 1927, used a test based on the adaptability of the circulation to quiet standing in one position for 15 minutes and changes in position. A graded scale derived from reclining heart rate, standing heart rate, general course of the heart rate during prolonged standing and the changes in systolic, diastolic, and pulse pressure while standing was employed.

In 1931, McCloy (25) introduced a cardiovascular test involving only the diastolic blood pressure and heart rate in a quiet standing position. The formula for scoring is (.89 S.D.P.) - (S.P.R.) + 16. Ratings above zero indicate a satisfactory state of health.

Graybiel and McFarland, (26) in 1941, considered the use of the tilt table in a test scored on the basis of (a) fainting, (b) the maximal fall in systolic blood pressure below that of the reclining level and (c) the minimal pulse pressure while in the tilted position.

In 1943, Starr (27) introduced a modified cardiovascular test based on pulse and blood pressure in recumbent and erect position, using ballistocardiographic data. The average change in heart rate was +18 and change in blood pressure was + 5 mm. Hg. From this he developed the following formula:

a = mean pressure change - 5

b = 8 - pulse rate change

Index = a + b

This test has been used to determine when a patient should resume exercise following illness.

E. <u>Cardiovascular and Physical Performance</u>: In these tests the subject is given work severe enough to tax the cardiovascular system. They had their origin in laboratories where work could be measured accurately by the bicycle ergometer or treadmill and cost determined by O_2 consumption, blood lactate and pulse rate.

In 1942, the Harvard Fatigue Laboratory standardized a treadmill test which was later adapted as a pack test (28) for out-of-doors by providing work equal to that of the treadmill test. The subject stepped up on a 16-inch box 30 times a minute for 5 minutes while carrying a pack of approximately 1/3 his body weight on this back. Hand grips at shoulder level were provided. This was further simplified as the Step Test without pack.

The Navy or Behnke Step Test described in 1943 is similar in type but more complicated because it is divided into 2 parts and requires several pulse counts.

Specific gravity has been employed by Behnke (6, 7) to separate fit and unfit men especially when they are heavy. Technical difficulties precluded its wide use at present.

Rifle firing has been tried as a measure of performance of infantrymen (1) but has several faults as an objective test.

VII. SUGGESTIONS FOR AN IMPROVED TEST

In Table 11 the 4 tests discussed in this report have been evaluated for each of the factors listed as important in an improved test. Arbitrary ratings range from satisfactory to absent. No test comes near fulfilling all the qualifications of an ideal test.

A. Neither step test taxes many components of fitness. The AAF Test taxes a number while the AGF Test taxes a large number of the components of fitness. It appears that more components can be tested only by multiplying the complexity of actual number of separate parts of a test.

B. Although both the Harvard and the Navy Step Test and the AAF Test involve a fairly high energy output they do so only for certain aspects of muscular exercise and thus cannot tax all components on a high energy level. The Step Tests evaluate high energy output for a few minutes only and the AAF Test does not really tax the performer. Even the AGF Test is unsatisfactory because several of its components do not require a high energy output.

C. The 5-minute limit of the Harvard Step Test can be completed by about 85% of men in good physical condition and beyond this dividing line further separation is lost as far as endurance is concerned. The Navy Step Test has a separate endurance phase though the scoring system reduces its value. The AAF Test does not measure endurance except over very short periods in the pull-ups and chins. In the AGF Test, endurance is measured fairly well by the 4-mile march after the 5 earlier test components.

D. Similarity of stress cannot be achieved where size, shape and aptitude influence performance; therefore, any test in which these factors are important loses some of its accuracy. Since, however, certain aspects of physique may be considered as elements of fitness, a test which may be influenced disproportionately by a physical characteristic fails to differentiate physique from physiologic status. A high score may be obtained by a tall, moderately fit man or a short, very fat one. Tasks which require special skills or coordination have a reduced value in any study where tests are repeated, for a learning curve may obscure true improvement. Thus, in evaluating fitness from test scores, it is important to know whether any peculiar physical trait exists. Scoring systems could introduce a correction for the effects of physique upon scores. Reasonably similar stress occurs in men walking, running and performing customary tasks. Thus the step tests are based on a somewhat artificial situation whereas at least some of the components of the other tests are significantly affected by size.

E. The effects of environment on fitness tests have not been studied systematically. It was found that an increase in altitude from 6000 feet to 9000 feet produced striking decreases in the Harvard Step Test and AAF Test scores. Such decreases in score gave only a poor indication of the distress produced by exercise and the relatively poor post-exercise condition of the subjects. Of course heat, rain, terrain and clothing may all exert a profound but as yet not measured effect upon performance. Unless

TABLE 11

An Ideal Test of Physical Fitness Should:	Harvard Step Test	Navy Step Test	AAF Test	AGF Test	Hypothetical Treadmill Test
1. Test chief components of fitness	x	x	Fair		Fair
2. Tax each component on high energy level	x	x	x	Poor	–
3. Measure endurance	Poor	Fair	x		
4. Put reasonably similar stress on all	Fair	Fair			
5. Show little environmental effect	Fair	Fair	Poor	Poor	
6. Consider physiologic cost	Fair	Fair	x	x	
7. Consider post-exercise condition	x	x	x	x	
8. Be independent of motivation	x	x	x	x	
9. Be reproducible		Poor	Fair	Fair	
10. Be simple to conduct			Poor	x	x
11. Be simple to evaluate	x	x	x	x	
12. Have normal distribution of scores		x	x	x	–
13. Have improving scores with improving fitness					–
14. Have small learning component	Fair	Fair	x	Fair	

further investigation results in use of factors of correction in the scores the test may be rendered unsatisfactory because of meteorological and environmental changes outside the control of the investigator which are not provided for by the scoring systems.

F. Physiologic cost is not even considered in the AAF and AGF Tests. It is considered only in terms of pulse rate in the step tests, but even this limited observation greatly increases the value of the test. It has been noted that performance in terms of endurance has most weight in the final score. The utility of blood pressure measurements is probably limited but an investigation of respiration and ventilation, even if only a count of respiratory rate,should be investigated.

G. No test takes into consideration the state of the subject after the test though it is obvious that a man who completes a task and collapses is not as fit as one who does the same task and remains in good condition.

H. No test is independent of motivation. In some tests it may actually dominate performance.

I. If a fitness test is not reproducible within reasonable limits it has little value in helping to judge fitness. Errors in procedure, faults of the scoring system, the presence of a large learning component in performance, acquired skill or ability to "beat the test" and variations of environmental factors influence work and efficiency. It is not rare that mere reproducibility signifies a fault in the scoring system as in the 4-mile march of the final AGF Test where more than 99% of the subjects finished on time although there was a wide scatter of times. No separation was made of these men although obviously there were readily appreciated differences among them. It may be argued with propriety that lack of reproducibility may simply indicate true change in fitness. In the absence of any final criterion of evaluation of fitness and lack of a quantitative measure of fitness in the aggregate it remains a matter of judgment as to whether varying scores indicate a fault of the test or a change in fitness.

J. In order that large numbers of men may be processed as rapidly and easily as possible, simplicity is one of the chief goals in fitness testing. It becomes a question of where oversimplification destroys the significance of a test. Since there is no final standard against which to judge, this can be decided only by the subjective evaluation of fitness.

Other factors remaining constant, the more elements there are in a test or battery of tests, the more likely it is to be a significant measure of true fitness. Information at hand does not allow a decision as to the precise point on the scale from simplicity to complexity where the most information can be gained for the least effort. There is more danger from oversimplification than from over complexity and the reductio ab absurdum of trying to learn almost everything by doing almost nothing is approached in some tests.

K. None of the tests is simple to evaluate because there is poor mutual intercorrelation and there is no quantitative measure of performance against which to evaluate each one singly. In the Colorado Test there was a fairly good correlation between the sum of the scores on the three tests and the company officers' ratings of fitness.

L. Only the Harvard Step Test approaches a binomial or normal distribution of scores; the others all show asymmetry, skewing or bimodality, This is frequently a fault of the scoring system rather than the test itself but in sit-ups and push-ups the limit of improvement in score before fitness has reached a peak partly defeats the purpose of the tests.

M. All tests seem to have improving scores with improving fitness though whether this is a parallel change cannot be stated.

N. The learning component is presumably small in any exercise which is usual in everyday life. Thus walking or running require little if any learning while sit-ups, pull-ups, chins, and burpees are calisthenic exercises in which learning may effect score improvement regardless of changes in actual condition. A learning phase in the sit-up test weakens its value considerably. The ingenuity used to "beat the score" and at the same time avoid extra effort is important but can hardly be measured.

O. A hypothetical treadmill test could be devised to satisfy most of the desiderata except for simplicity in apparatus and conduct of the test.

VIII. TEST METHODS AND SCORING PROCEDURES

The methods actually used in administrating the various tests are given in detail because slight variations may affect the score. None of the tests is definitive and changes in directions and scoring systems are still being made by the proponents of some tests.

A. Harvard Fatigue Laboratory Step Test:

1. Stepping boxes 20 inches in height were prepared. The subjects lined up in front of the boxes, stripped to their underwear and socks or bare feet.

2. A pendulum, consisting of a weight on a string 39 inches in length, hung from an improvised scaffold, indicated the required rhythm.

3. At the signal "start" the subject placed one foot on the box, stepped up placing the other foot on the box, straightened the legs and back, and immediately stepped down. At exactly 2-second intervals, the signal, "Up!" was given by the observer. The rhythm was maintained by giving the count "Up-2-3-4, Up-2-3-4". Some subjects responded better to a tap on the back or arm at the required "stepping up" time, while others maintained satisfactory cadence by watching the pendulum. The same foot was used to initiate stepping up and stepping down. The subject was instructed to "lead off" with the same foot each time, although one or two changes during the test were permitted. The swinging of the arms was allowed, but the pressing of the hands against the thighs was forbidden.

4. The "time" began when the subject started exercising. If the subject fell behind the rhythm for 20 seconds without it being regained, he was stopped. No men were allowed to continue for more than 5 minutes. Time was recorded by a stop watch.

5. Upon the termination of exercise the subject was immediately seated and time was counted.

6. The pulse rate was counted from 1 minute to 1 minute 30 seconds following completion of exercise.

7. The duration of effort and the number of heart beats during the 30-second interval were recorded.

8. The score was read from a chart. (Table 12).

B. Army Air Forces' Test: The AAF Test is composed of 3 elements: The sit-up, the pull-up or chin and the shuttle-run. The test subjects wore regulation field uniform and combat shoes throughout the entire test. The jacket was kept on if a 2-piece uniform was used.

1. Sit-Up: The subject began the test lying supine on the ground with hands placed behind head. He sat up, then extended his arms to touch toes with hands, keeping his knees straight and then resumed supine

TABLE 12

SCORING OF STEP TEST

Duration of Effort	Heart Beats from 1 Min. to 1-1½ Min. in Recovery										
	40-44	45-90	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90 over
0' - 29"	5	5	5	5	5	5	5	5	5	5	5
0' 30" - 0' 59"	20	15	15	15	15	10	10	10	10	10	10
1' 00" - 1' 29"	30	30	25	25	20	20	20	20	15	15	15
1' 30" - 1' 59"	45	40	40	35	30	30	25	25	25	20	20
2' 0" - 2' 29"	50	50	45	45	40	35	35	30	30	30	25
2' 30" - 2' 59"	70	65	60	55	50	45	40	40	35	35	35
3' 0" - 3' 29"	85	75	70	60	55	55	50	45	45	40	40
3' 30" - 3' 59"	100	85	80	70	65	60	55	55	50	45	45
4' 0" - 4' 29"	110	100	90	80	75	70	65	60	55	55	50
4' 30" - 4' 59"	125	110	100	90	85	75	70	65	60	55	50
5'	130	115	105	95	90	80	75	70	65	65	60

Find appropriate line for duration of effort; then find the appropriate column for pulse count; read off the score where the line and column intersect.

Below 50 - Poor general physical fitness
50 - 80 - Average general physical fitness
Above 80 - Good general physical fitness

position. No counterweight was used. The subject was not allowed to "bounce" himself up. He kept his hands behind his head until erect and did not rest between sit-ups. Sit-ups were repeated as frequently as possible, but not more than 114 times. The number of complete sit-ups was recorded.

2. Pull-Up or Chin-Up: The subject grasped the bar with the palms facing inward and hung free with the arms fully extended. He then began the exercise by pulling himself down so that arms were fully extended. This was repeated as many times as possible. No kicking or swinging was permitted. The number of complete pull-ups was recorded. There was no time limit. Incomplete pull-ups were not counted.

3. Shuttle Run (300 yards): Two poles were set up in level ground 60 yards apart, the timer at one pole, the subject at the other. At the starting signal, the timer started his watch or noted the time if no stop watch was available, and the subject started his run. The poles were rounded but not touched. Five lengths of 60 yards constituted the test run. The time in seconds was recorded, fractions of seconds being converted to the next full second.

4. Scoring: The score is computed from Table 13.

C. <u>Army Ground Forces' Test</u>: This test is a battery of 6 different tests: the push-up, the 300-yard run, the burpee, the 75-yard pig-a-back, the 70-yard zigzag and the 4-mile march.

Subjects went from one event to another without pause until the 4-mile march, before which they had a half hour rest. Events were run in the order listed. Men wore field uniforms and combat boots throughout the entire test. During the 4-mile march men carried field equipment weighing 30 pounds. (See Table 14 for scoring.)

1. Push-Up: From the leaning rest position, the arms were bent at the elbow until chin and chest were near the ground with the body rigid. The body was raised by straightening the arms. The exercise was repeated as many times as possible. There was no cadence or time limit. Push-ups accomplished by bending or rocking body were not counted. The number of push-ups was recorded.

2. Three-Hundred-Yard Run: The run was 150 yards around a marker and return to the starting line. Time was recorded in seconds, raising fractions of seconds to the next full second.

3. Burpee: From position of attention subject bent to squatting position. The hands were placed on ground inside knees and at the same time legs were extended straight to the rear, the squatting position was resumed and then the position of attention. The exercise was repeated as many times as possible in 20 seconds. The number of complete burpees was recorded.

4. Seventy-Five-Yard Pig-a-Back: Subjects carried men of approximately their own weight. Men who fell down were allowed to repeat. Time in seconds was recorded, raising fractions to next full second.

TABLE 13

SCORING OF ARMY AIR FORCES TEST

Sit-Ups		Pull-Ups		Shuttle-Run		Sum of Scores	Final Fitness Rating
No.	Score	No.	Score	No.	Score		
114	100	23	100	35	100	300	100
108	98	22	99	36	95	290	98
102	96	21	97	37	90	280	96
96	94	20	94	38	88	270	95
90	92	19	90	39	85	260	93
84	88	18	86	40	83	250	90
78	83	17	82	41	80	240	85
72	78	16	78	42	78	235	81
70	75			43	75	230	78
69	74					225	75
66	73	15	74	44	74	224	74
63	72	14	70	45	72	220	73
60	71			46	70	215	72
57	70	13	66	47	67	210	70
54	68			48	64	205	68
51	66	12	62			200	66
50	64					195	65
						190	64
49	63			49	63	189	63
48	61	11	58	50	62	185	61
45	58			51	60	180	60
42	55	10	54	52	58	175	58
39	52			53	55	170	57
36	51	9	50	54	52	165	55
33	49			55	50	160	54
31	47	8	47	56	47	155	52
						150	50
						145	48
						140	47
30	46	7	44	57	46	139	46
				58	44	135	45
27	43	6	41	59	42	130	44
				60	40	125	42
24	40	5	38	61	38	120	40
				62	36	115	38
21	37	4	35	63	34	110	36
						105	35
20	34					100	34
19	33			64	33	99	33
18	30	3	32	65	25	90	30
15	27			66	22	80	27
12	25	2	29	67	20	70	23
9	22			68	18	60	20
6	13	1	26	69	15	50	17
3	5			70	13	45	15
				71	10	40	10

Instructions: The appropriate numbers are totaled and the final fitness rating is read from the last column. In the number of sit-ups where there may not be a corresponding number on the score table, take it to the closest number.

TABLE 14

SCORING OF THE ARMY GROUND FORCES TEST

Event	Scoring	Weighting Factor
1. Push-Ups	3% for each push-up	1
2. 300-Yard Run	45 seconds or under, score 100%. Deduct 4% for each second (or fraction) over 45 seconds.	2
3. Burpee	9% for each complete burpee	1
4. 75-Yard Pig-a-back	20 seconds or under, score 100%. Deduct 4% for each second (or fraction) over 20 seconds.	2
5. 70-Yard Zigzag	30 seconds or under, score 100%. Deduct 4% for each second (or fraction) over 30 seconds.	1
6. 4-Mile March	For straggling during 1st mile, deduct 8%; during 2nd mile 6%; 3rd mile 4%; 4th mile 2%. At finish deduct 5% for each minute (or fraction) over 50 minutes up to 5 minutes. Failing to finish score, zero. Penalties for any straggling are additive and are added to penalty for failure to finish on time. Straggling shall be construed as more than 1 minute late at each mile marker except at finish where men must be on time.	3

The score achieved on each event is multiplied by its weighting factor to give the weighted score for event. The weighted scores are added, divided by 10 (the sum of the weighting factors) to give the final score for the Army Ground Forces Test.

Assessment of Fitness, rating from final score:

Below 70	Unsatisfactory
70 - 77	Satisfactory
78 - 87	Very satisfactory
88 - 94	Excellent
94 or over	Superior

5. Seventy-Yard Zigzag: Subjects ran 10 yards, crawled 10 yards, ran 10 yards, crept 10 yards, ran 10 yards, jumped 10 yards and ran 10 yards. At the end of each run, except the last two, the subject "hit the ground". The jumps were five feet from center to center of the islands which were 2 feet in diameter. Six jumps, landing on both feet and keeping feet together, were required to cross the 10-yard interval. Direction of course changed 45 degrees each 10 yards, alternating right and left turns. Subjects did not dive when "hitting the ground" but crawled and crept the full 10 yards. Time was recorded in seconds, raising fractions to next full second.

6. Four-Mile March: As each group completed the first 5 components, it assembled with full field equipment and marched over a 4-mile measured course. Times were recorded for each mile of the courses as well as the total time, if more than 50 minutes.

D. Navy Step Test or Behnke Test: This test consists of two elements: a short period of exercise to elicit pulse rate response and a sustained period of moderate exercise to measure muscular endurance. Equipment comprised a box exactly 18 inches in height, a stop watch and a pendulum. The subject wore shorts or underwear, without shoes.

1. Heart Rate Response to Moderate Exercise:

a. The sitting pulse rate was taken after the subject had been seated quietly for 2 or 3 minutes, at least twice to be certain that it was approximately stable.

b. The subject then stood and placed one foot on the step, maintained it there throughout the test.

c. On a signal from the observer, the subject stepped up and down in time with the pendulum 20 times in 30 seconds. The subject stepped precisely with the signal and straightened the knee of the lifted leg as the other foot was placed firmly on the box. At the completion of 20 step-ups the subject sat down.

d. The pulse from 5 seconds to 20 seconds after completion of exercise was converted to rate per minute. The pulse was again recorded from 2 minutes, to 2 minutes 15 seconds following exercise, and converted to rate per minute.

2. Endurance Time and Post-Exercise Heart Rates.

The endurance run began 15 seconds after last pulse reading or 2 minutes 30 seconds after previous exercise. The subject continued the standard exercise until a sharp break in rhythm or exhaustion occurred. Time was recorded to the nearest second.

3. Scoring. The score is determined in accordance with directions given in Table 15.

TABLE 15

SCORING THE NAVY OR BEHNKE TEST

The test is evaluated in terms of two components, the cardiovascular score and the endurance time.

The cardiovascular score is calculated by means of the following equation:

$$C.\,S. = (B - 70) + 3\,(C - A),$$

where A = sitting pulse rate per minute

B = pulse rate per minute immediately after exercise (5 sec. to 20 sec.)

and C = recovery pulse per minute (120 sec. to 135 sec. count).

Also, when A is 70 or less, it is considered to be 70 and

when $(C - A)$ is 4 or less, the expression $3\,(C - A)$ is considered to be 0.

Interpretation of the result and values:

Cardiovascular Score	Rating
Above 74	Poor
51 - 74	Fair
0 - 51	Good

The endurance time is considered to be directly proportional to the physical training of the individual. Interpretation of the endurance time values:

Below 60 sec.	Poor
60 - 120 sec.	Fair
Above 120 sec.	Good

The physical condition as evaluated by these tests is expressed as an index:

$$\text{Step Index} = \frac{\text{Endurance Time}}{\text{Cardiovascular Score}} \times 10$$

In this equation, if the cardiovascular score is 50 or less, it is considered to be 50. An arbitrary set of standards for rating fitness is given below:

Step Index	Rating
Below 8	Poor
8 - 12	Fair
Above 24	Good

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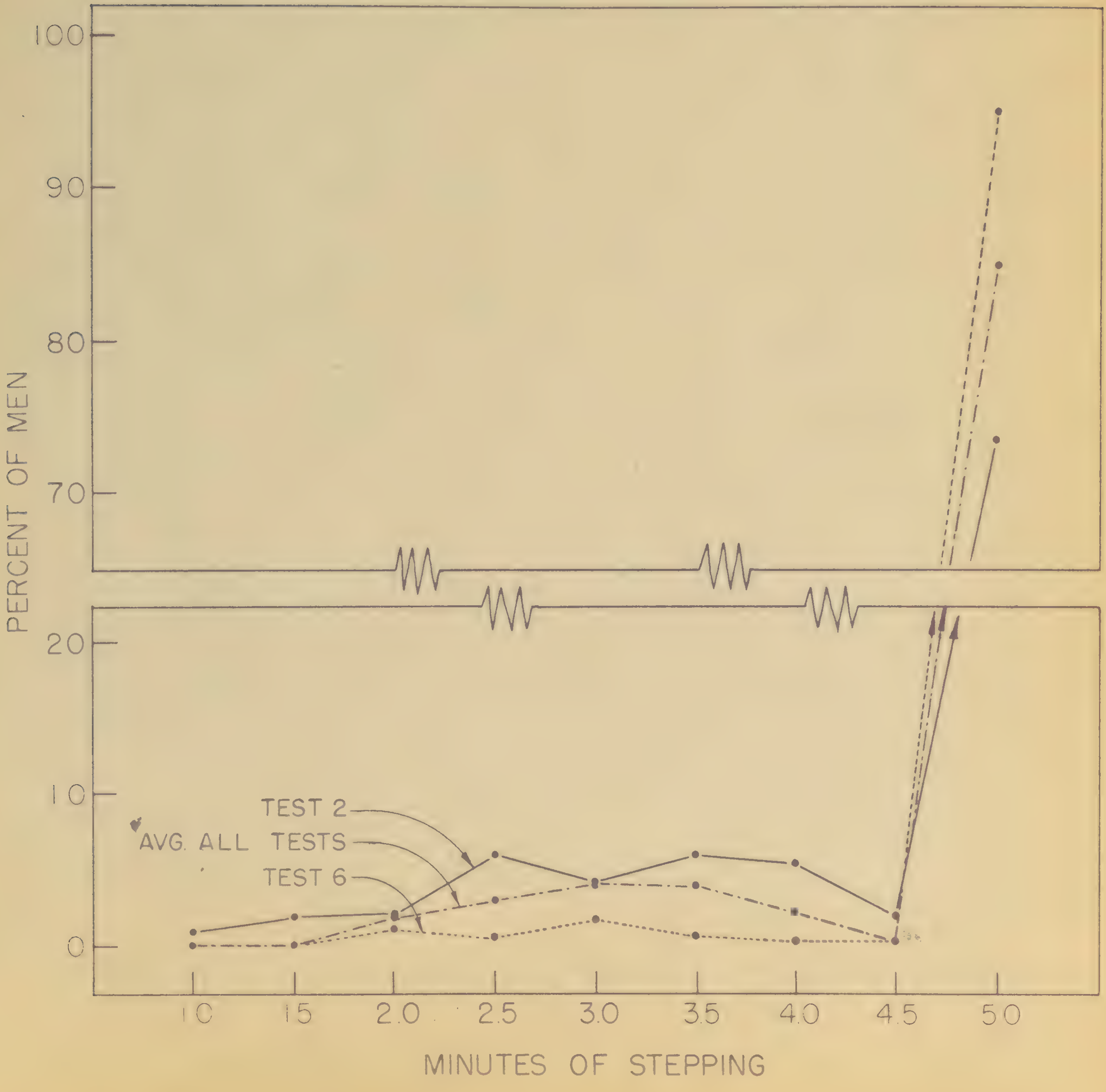
X. FIGURES

FIG. I

DISTRIBUTION OF PERFORMANCE TIME ON HARVARD STEP TEST



SCORING SYSTEM OF HARVARD STEP TEST

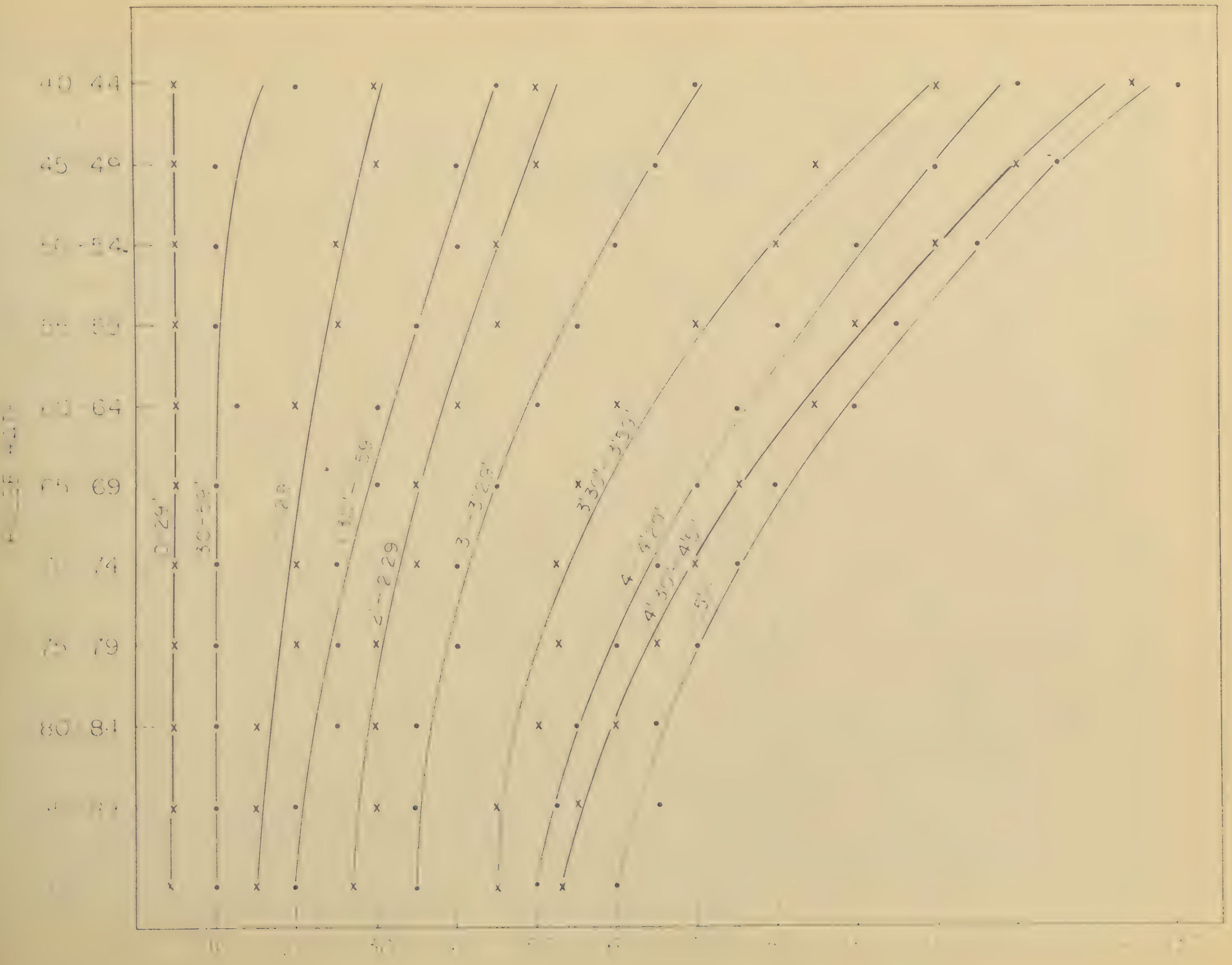


FIG 3

DISTRIBUTION OF PULSE RATE FOR MEN COMPLETING FULL FIVE MINUTES ON STEP TEST

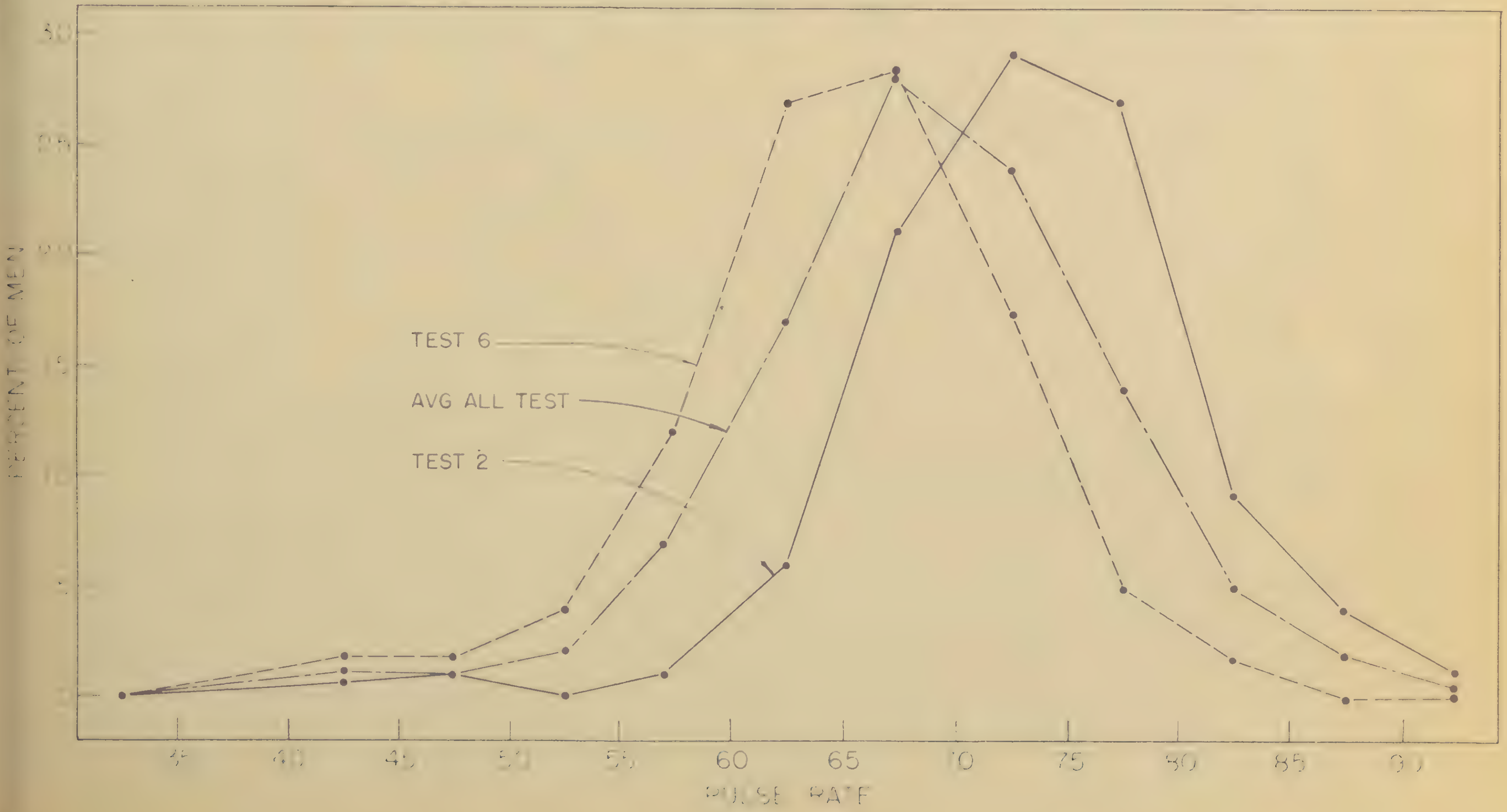


FIG 4 DISTRIBUTION OF SCORES

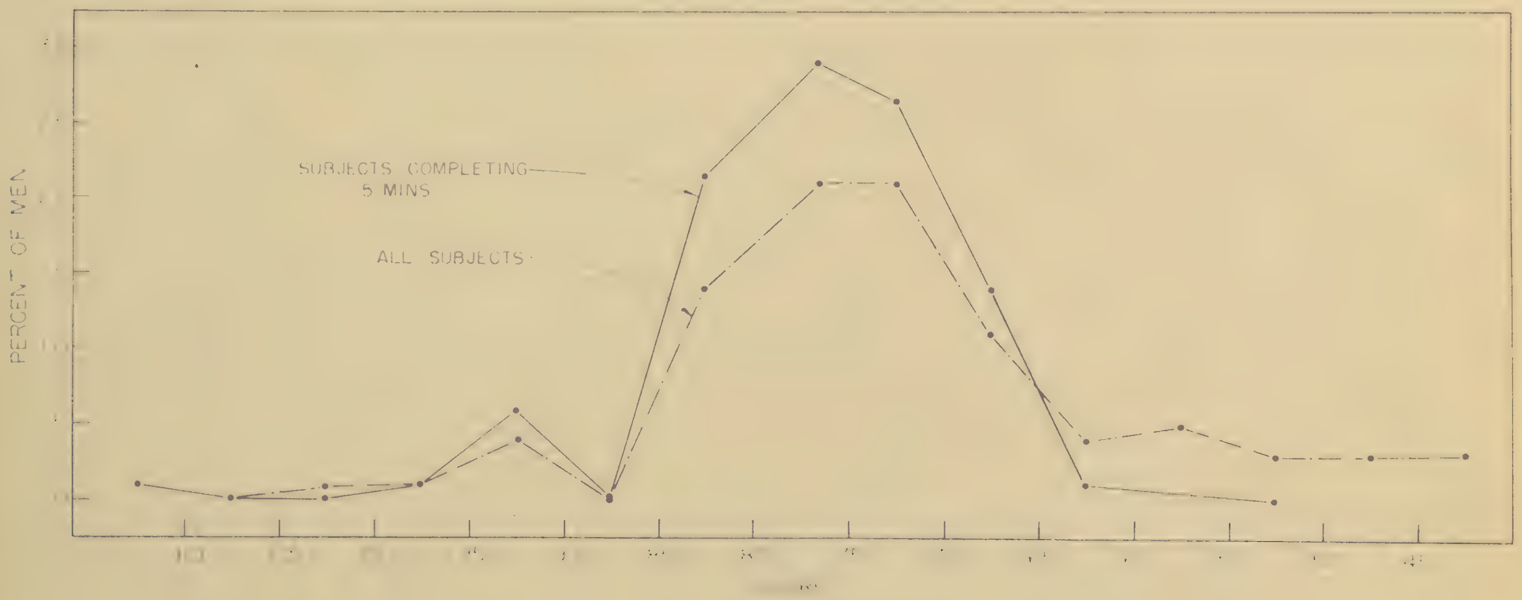
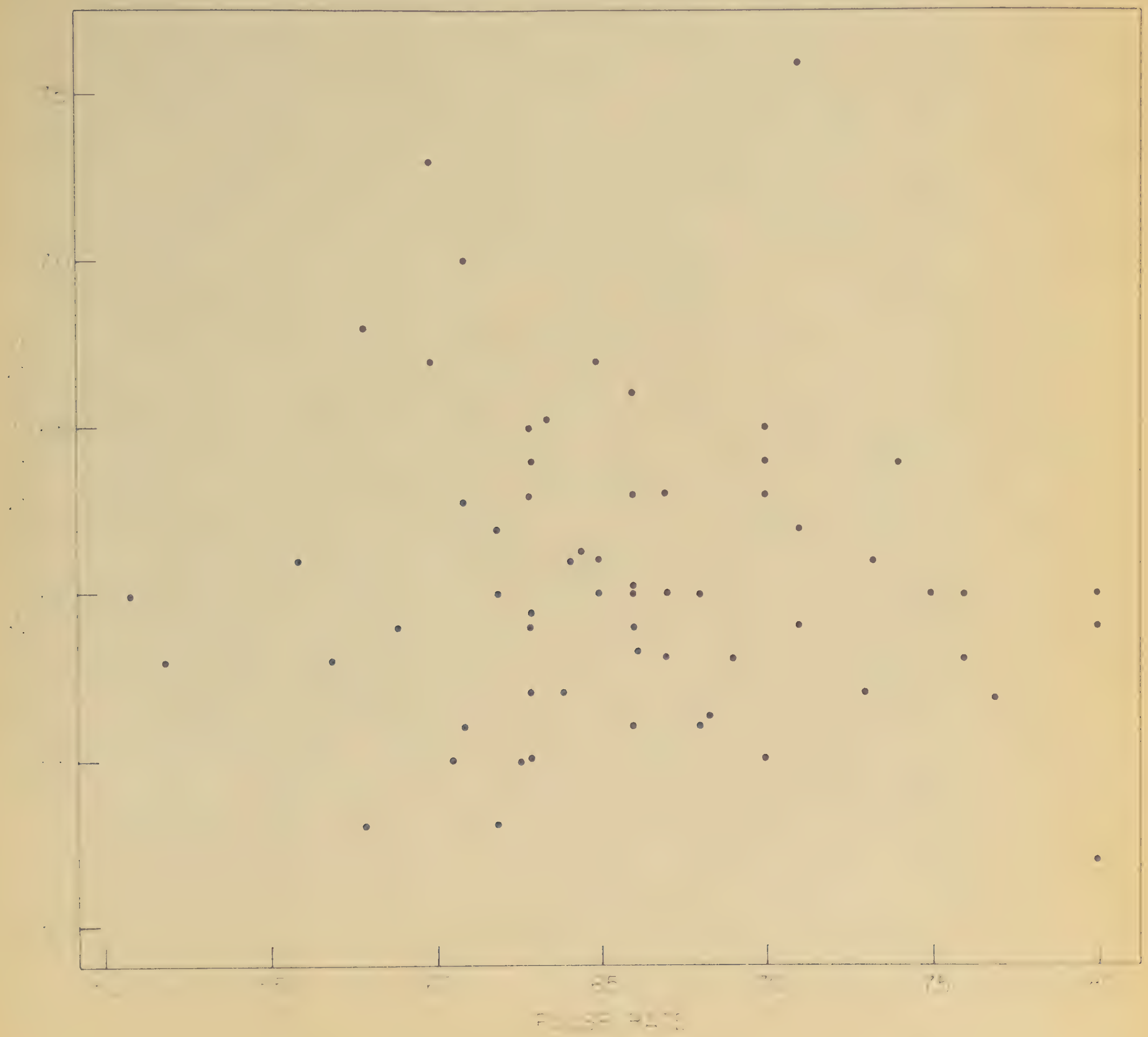


FIG 5

CORRELATION OF TIME ON AAF 300 YD. RUN WITH PULSE RATE RESPONSE ON HARVARD TEST



DISTRIBUTION OF SCORES ON STEP TEST AMONG GROUPS OF DIFFERING FITNESS

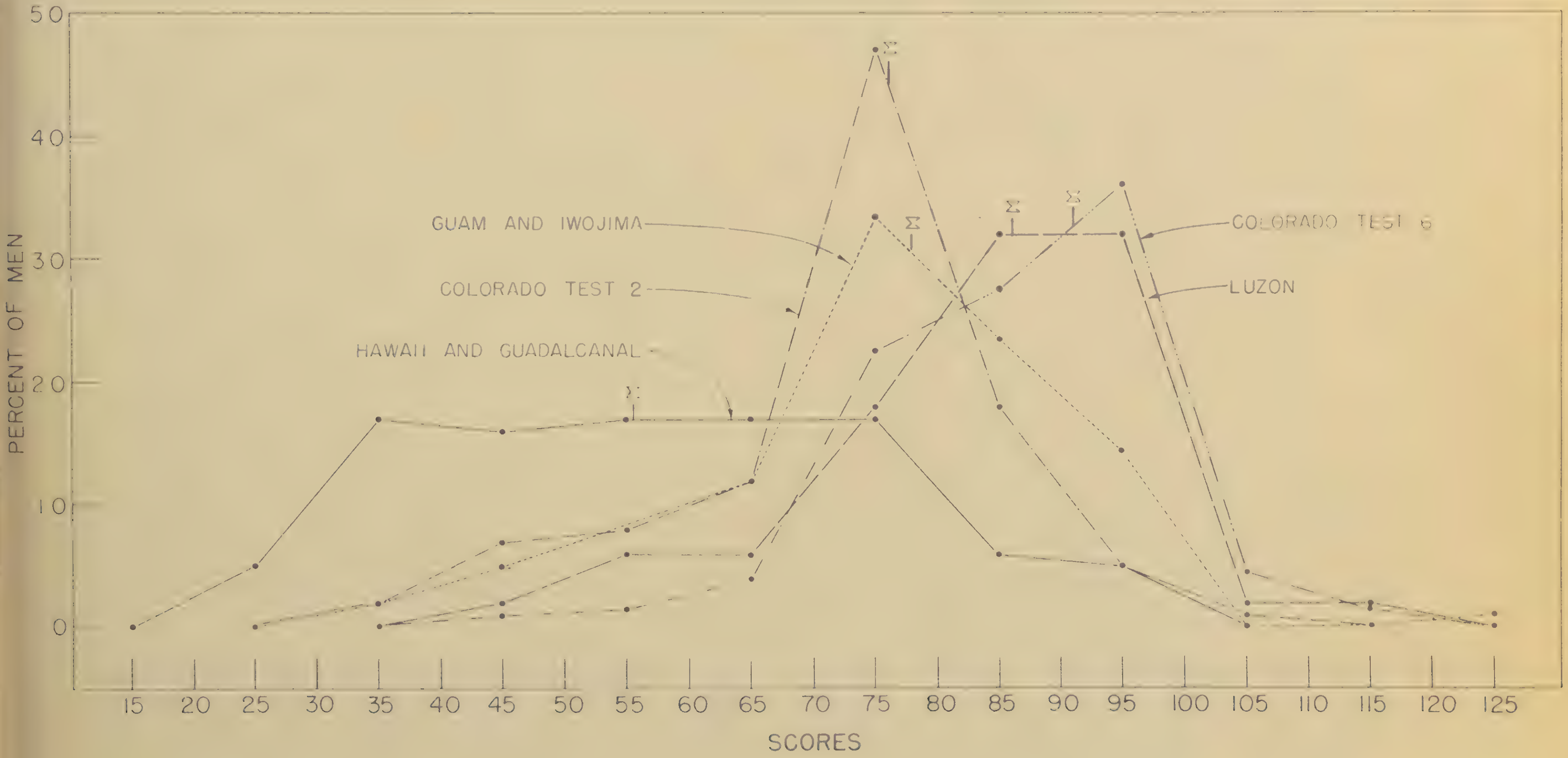


FIG. 7

DISTRIBUTION OF RUNNING TIME IN AAF
SHUTTLE RUN

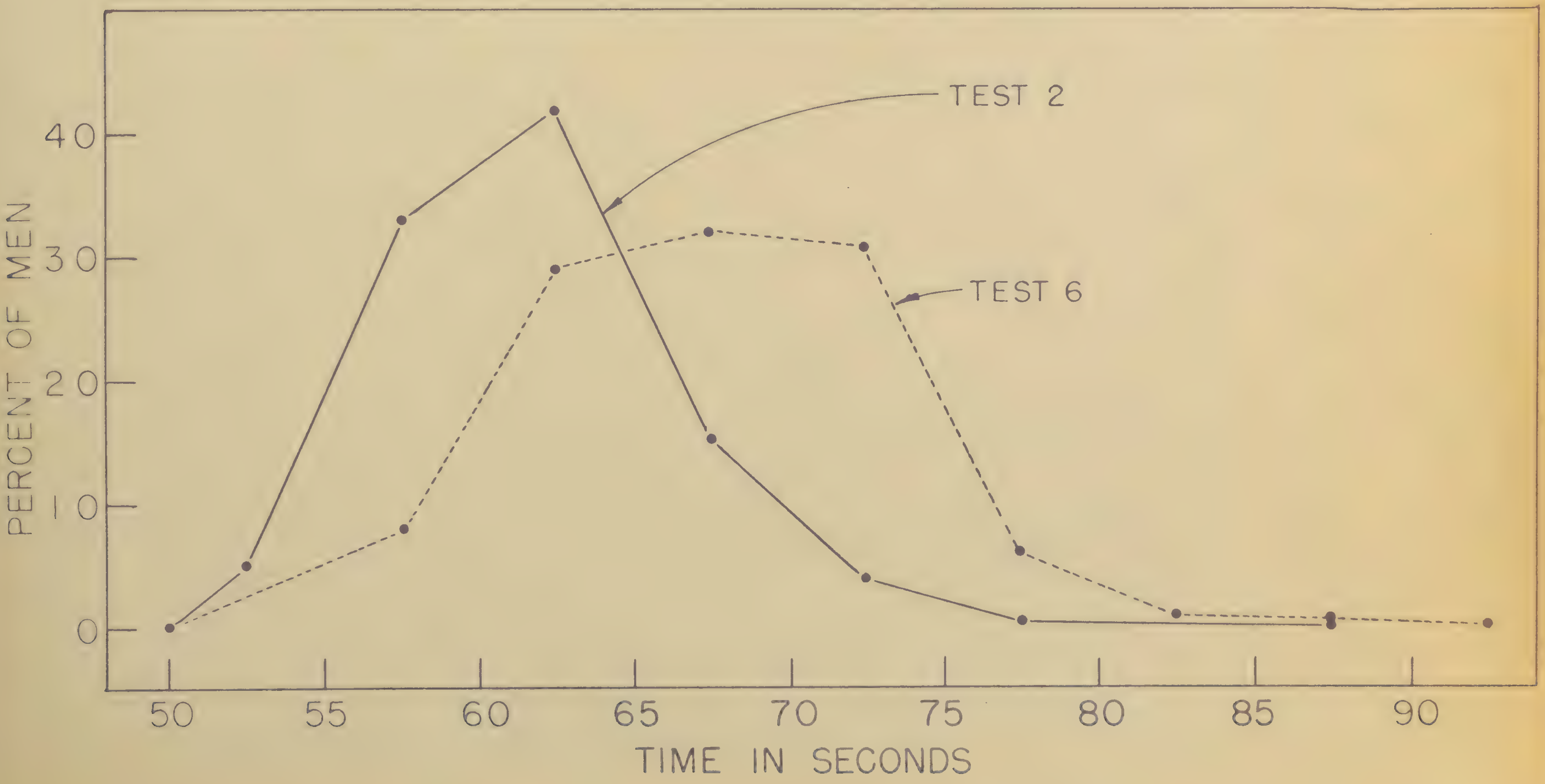


FIG. 8

SCORING CHART OF AAF SHUTTLE RUN

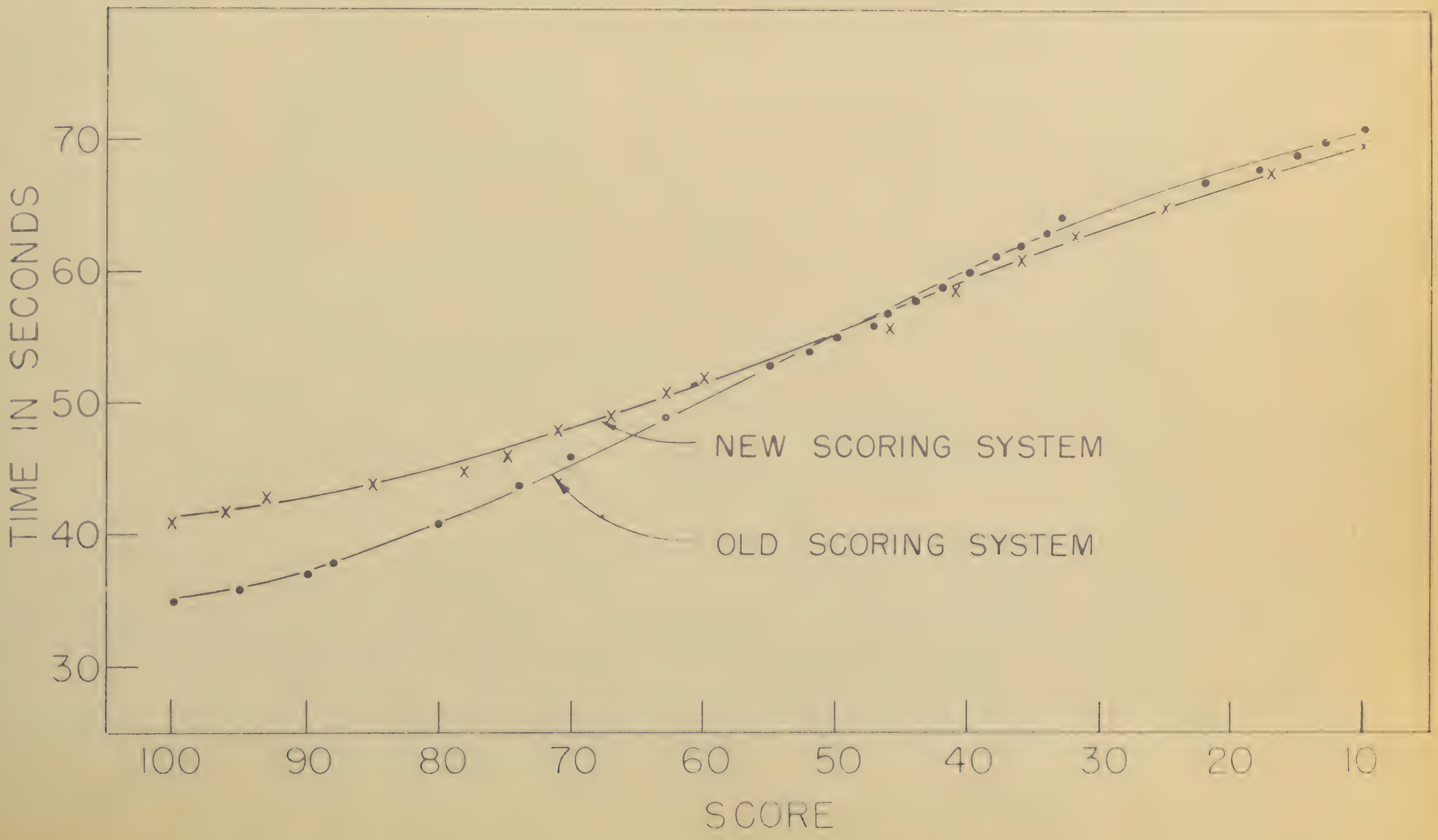


FIG. 9

DISTRIBUTION OF NUMBER OF SIT-UPS

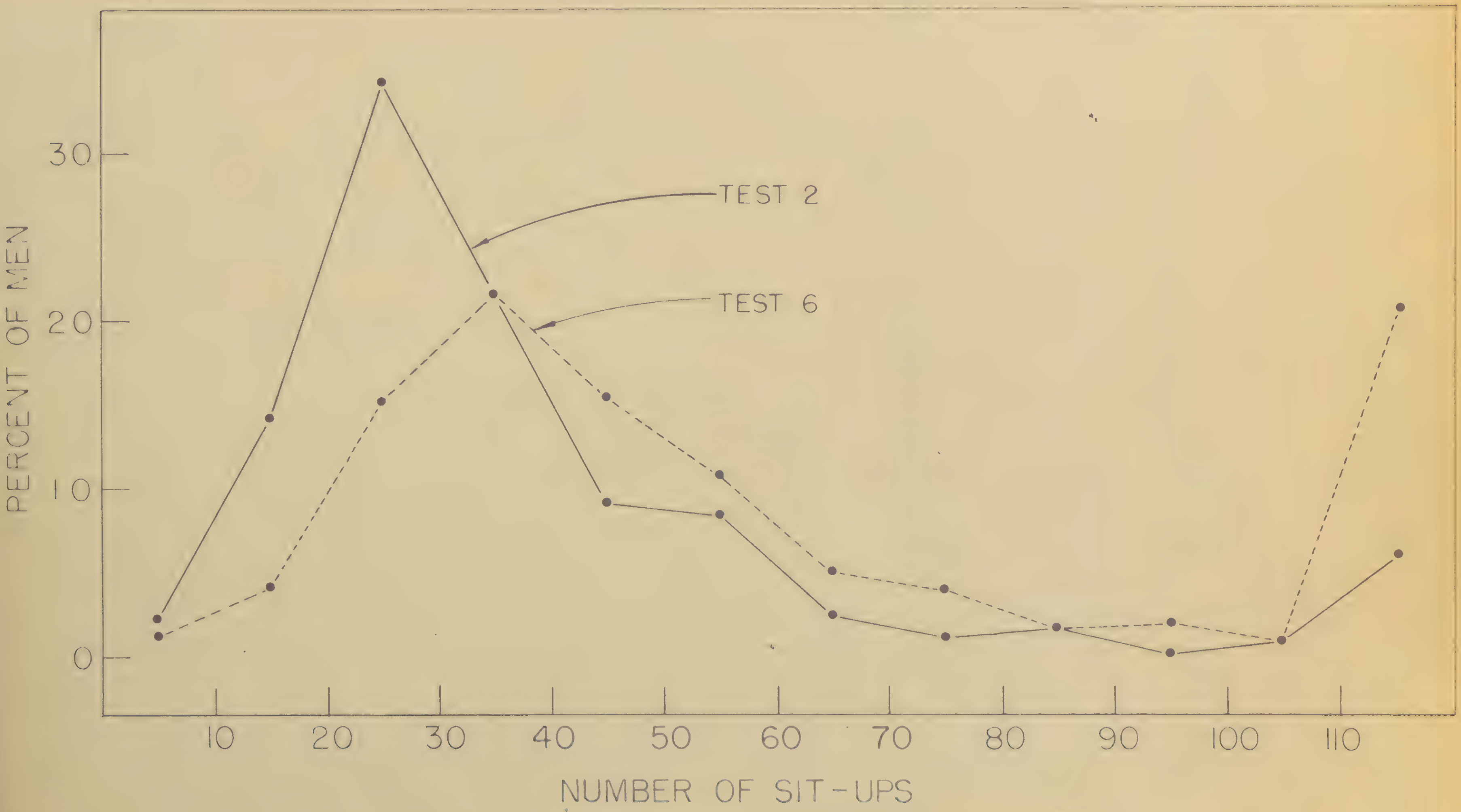


FIG. 10

SCORING CHART FOR AAF SIT-UPS

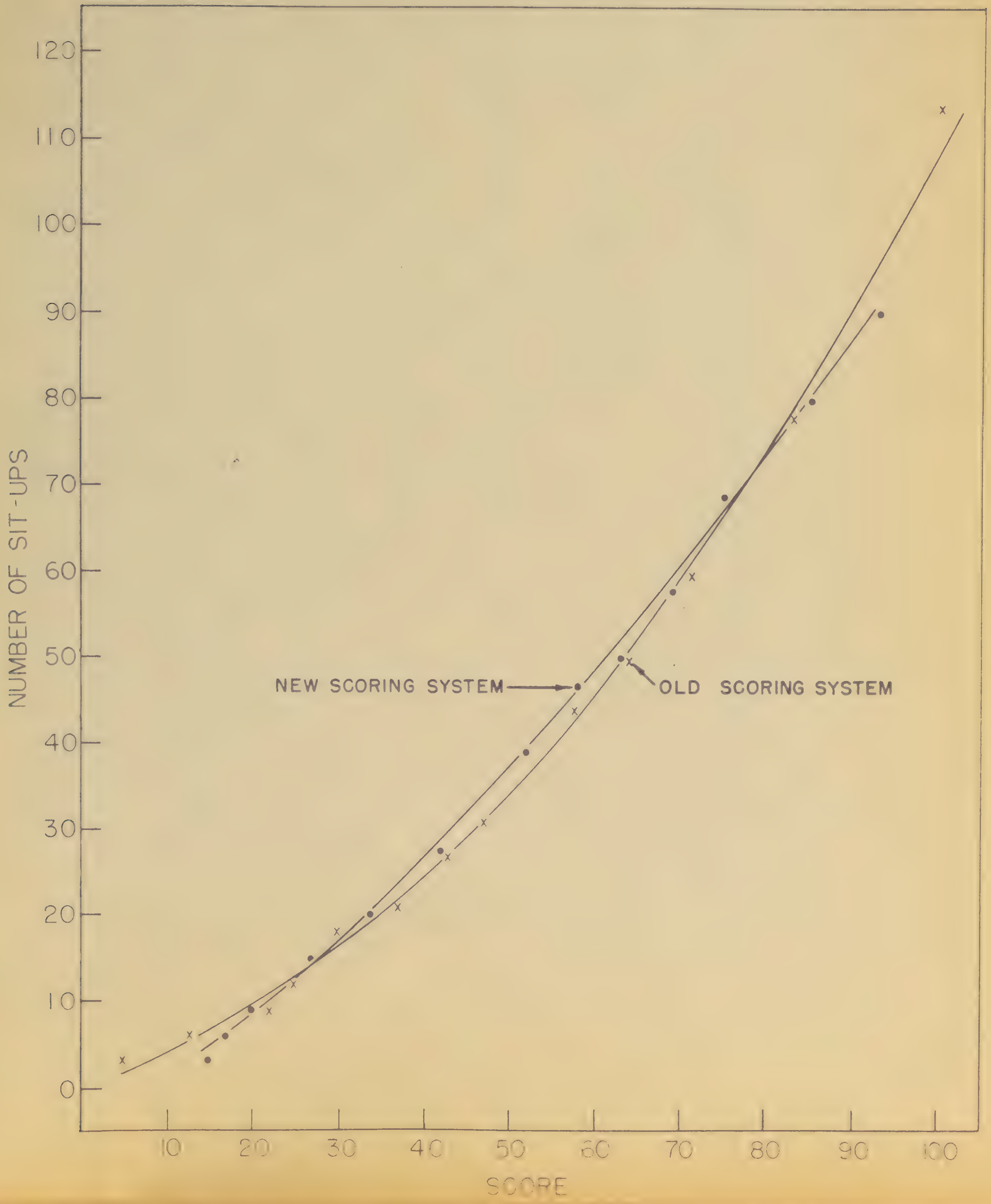


FIG. 11

DISTRIBUTION OF NUMBER OF PULL-UPS

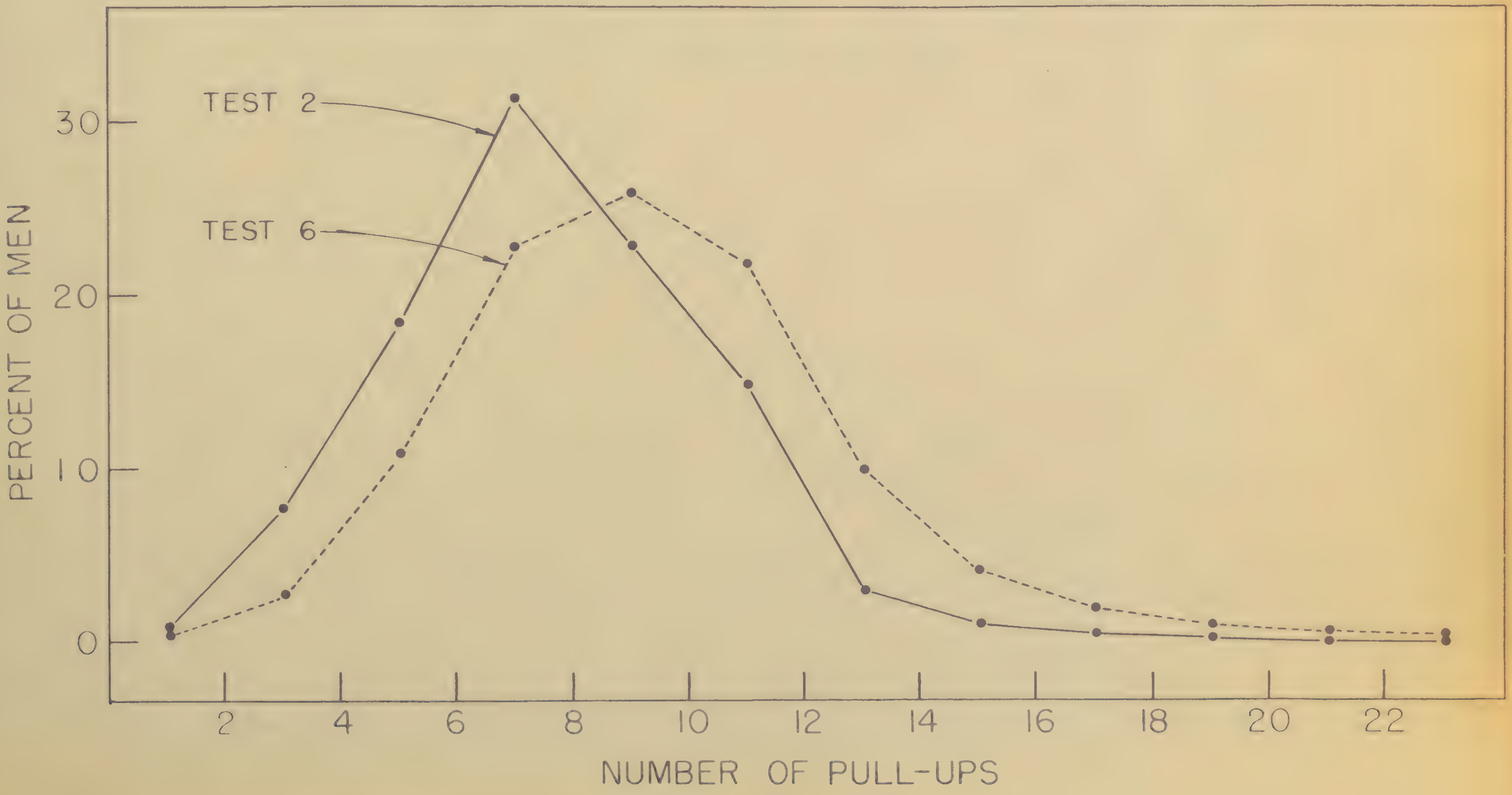


FIG 12

DISTRIBUTION OF SCORE ON AAF TESTS

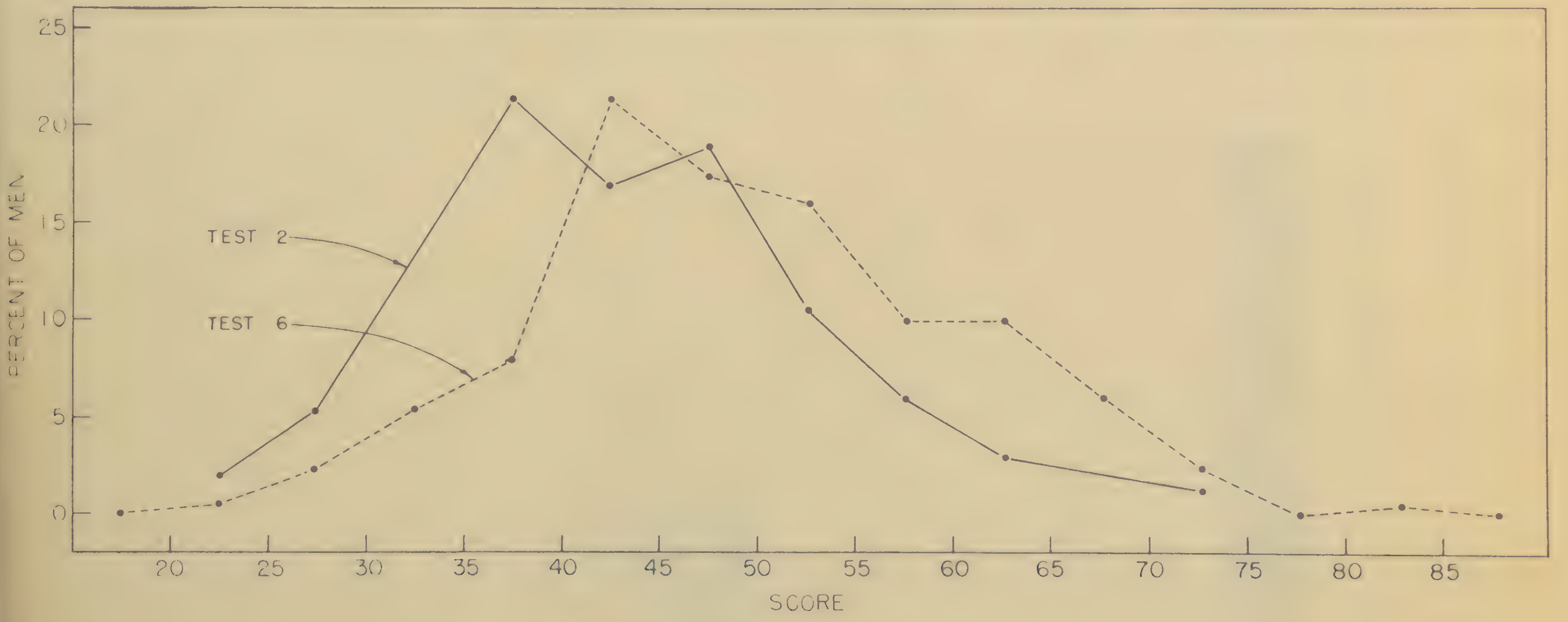


FIG 13

PERFORMANCE ON FOUR MILE MARCH

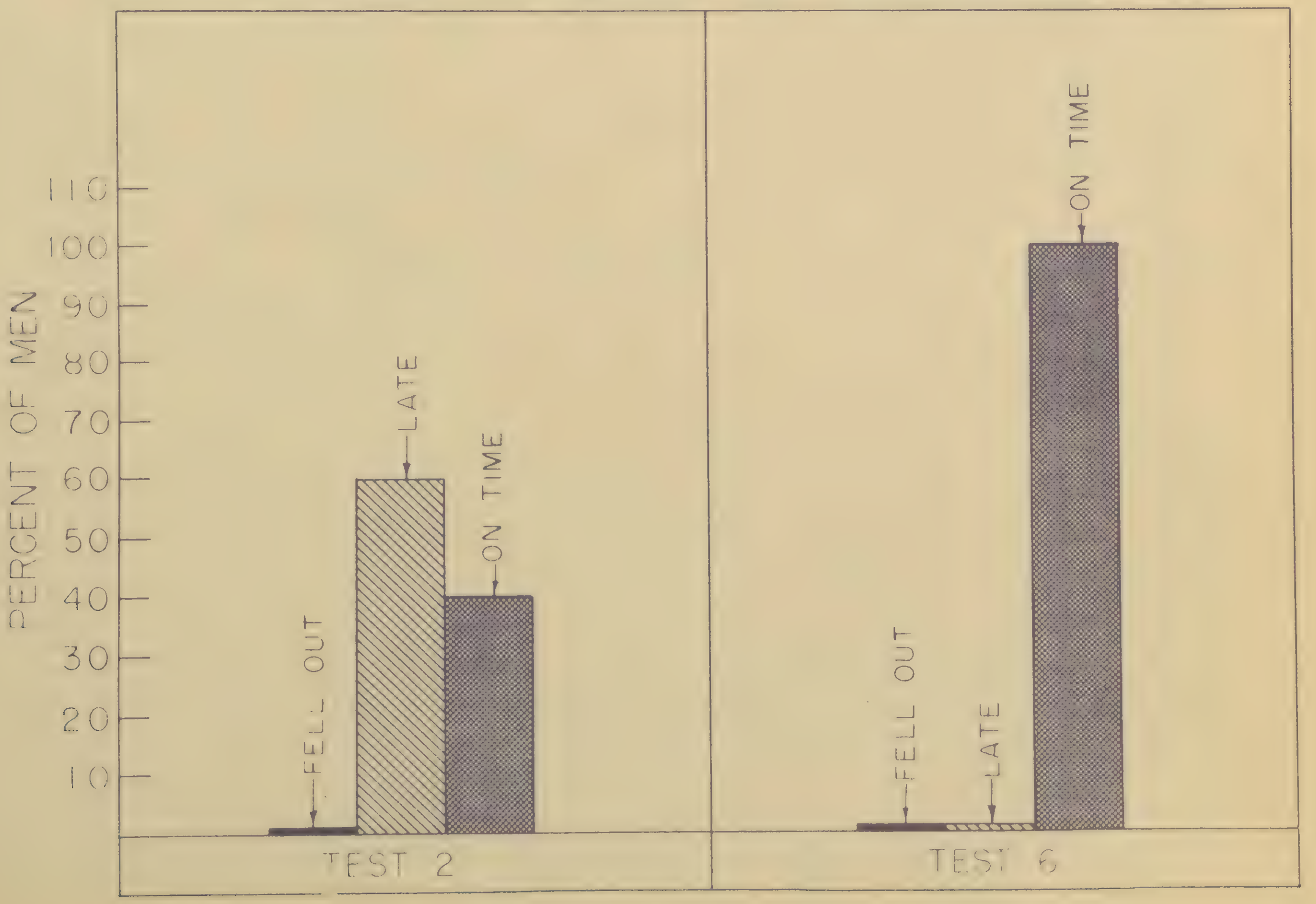


FIG 14

PERFORMANCE DISTRIBUTION ON 300 YARD RUN

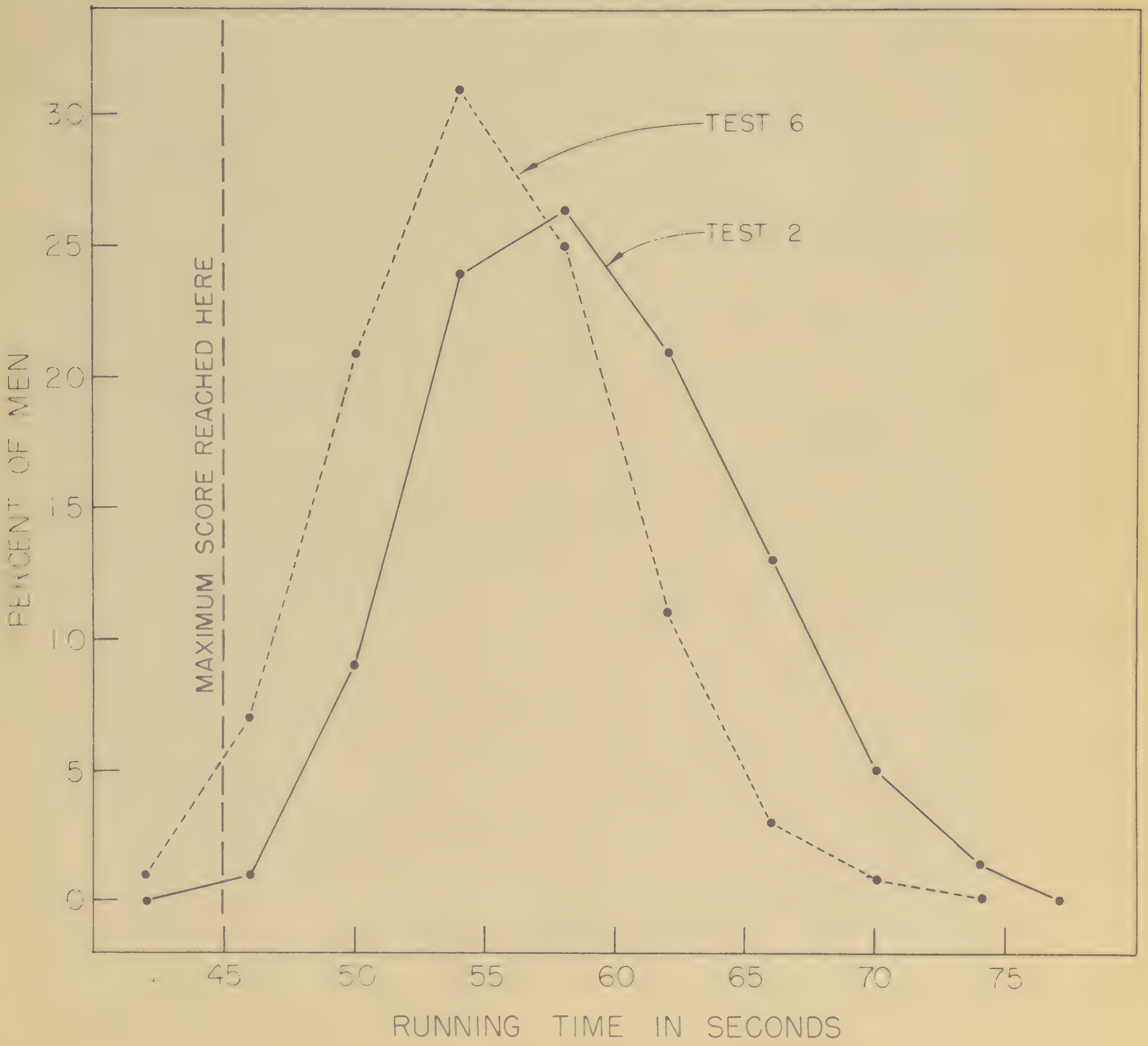


FIG 15

PERFORMANCE DISTRIBUTION ON PIG-A-BACK RUN

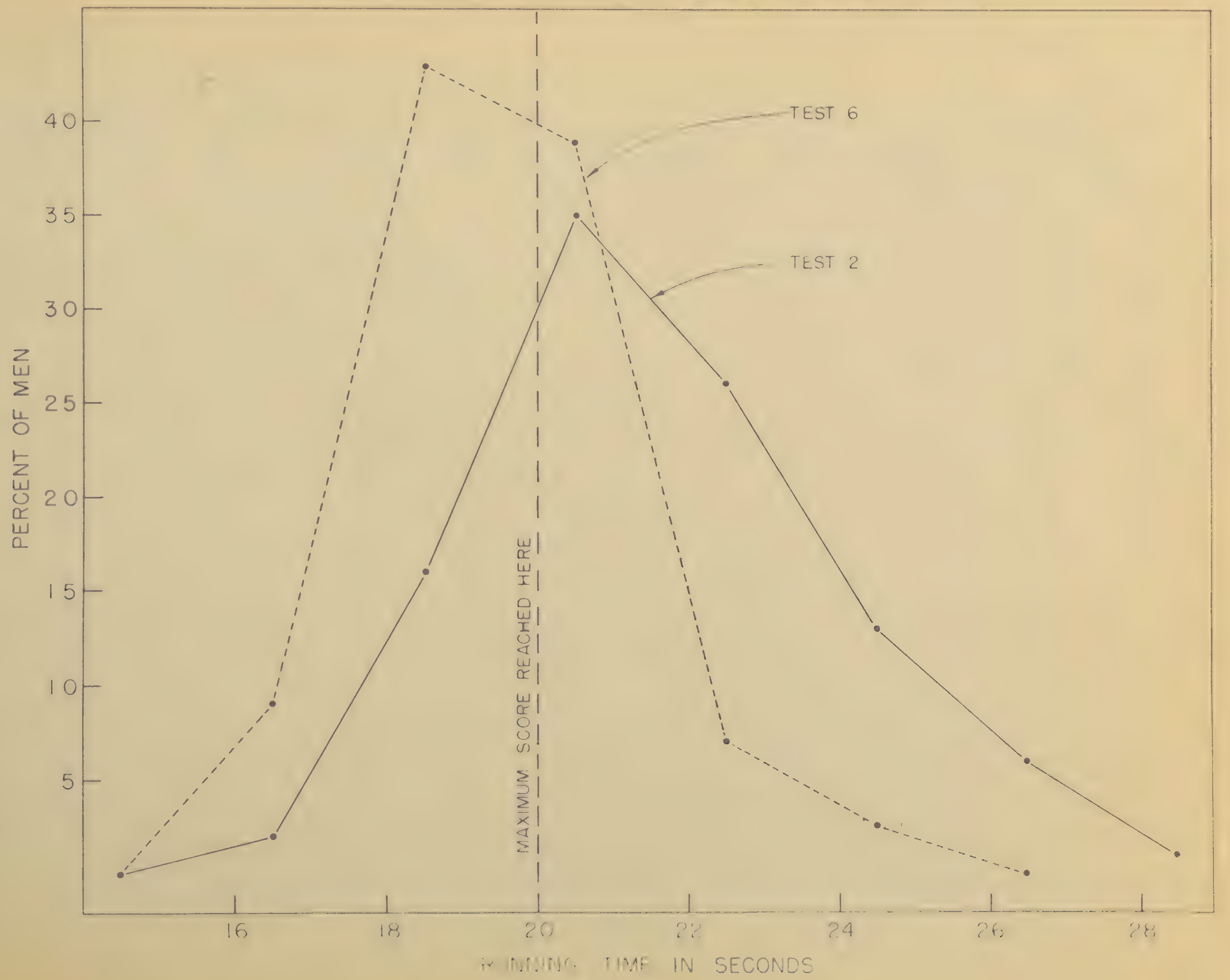


FIG 16

PERFORMANCE DISTRIBUTION ON ZIG-ZAG RUN

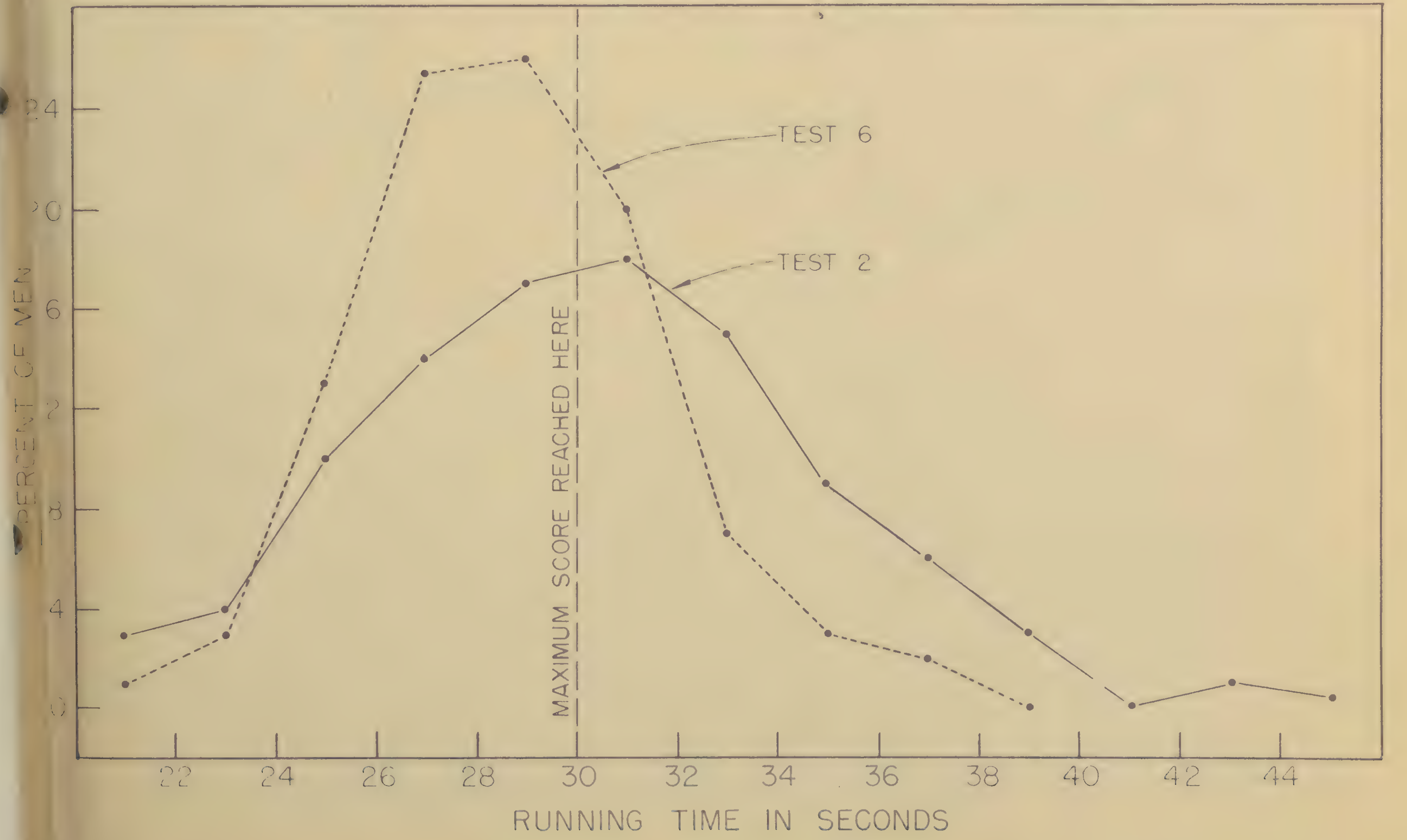


FIG. 17

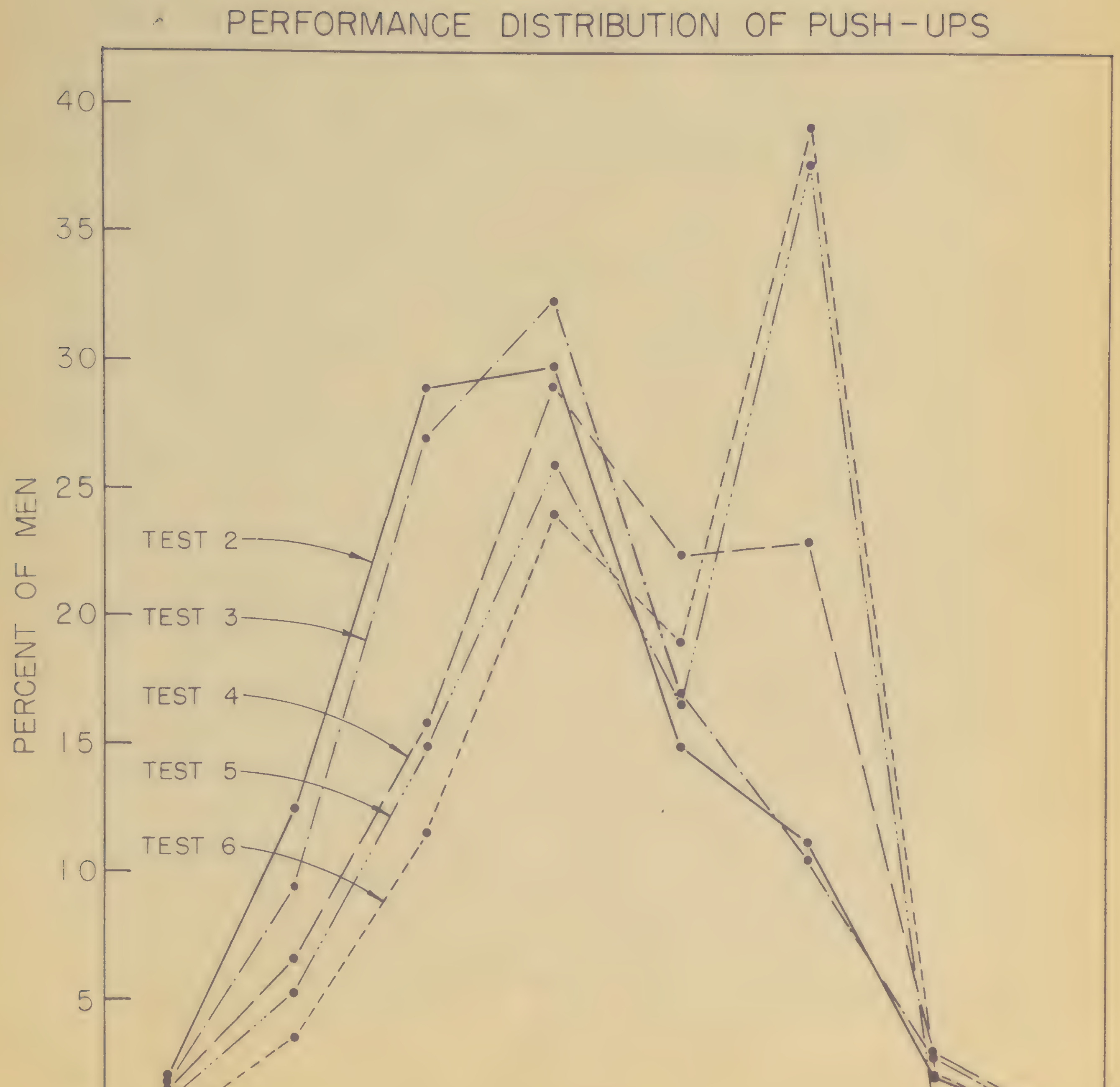

PERFORMANCE DISTRIBUTION OF PUSH-UPS
PERCENT OF MEN
40
35
30
25
20
15
10
5
0
TEST 2
TEST 3
TEST 4
TEST 5
TEST 6
10
15
20
25
30
35
40
NUMBER OF PUSH-UPS

FIG 8

PERFORMANCE DISTRIBUTION OF BURPEES

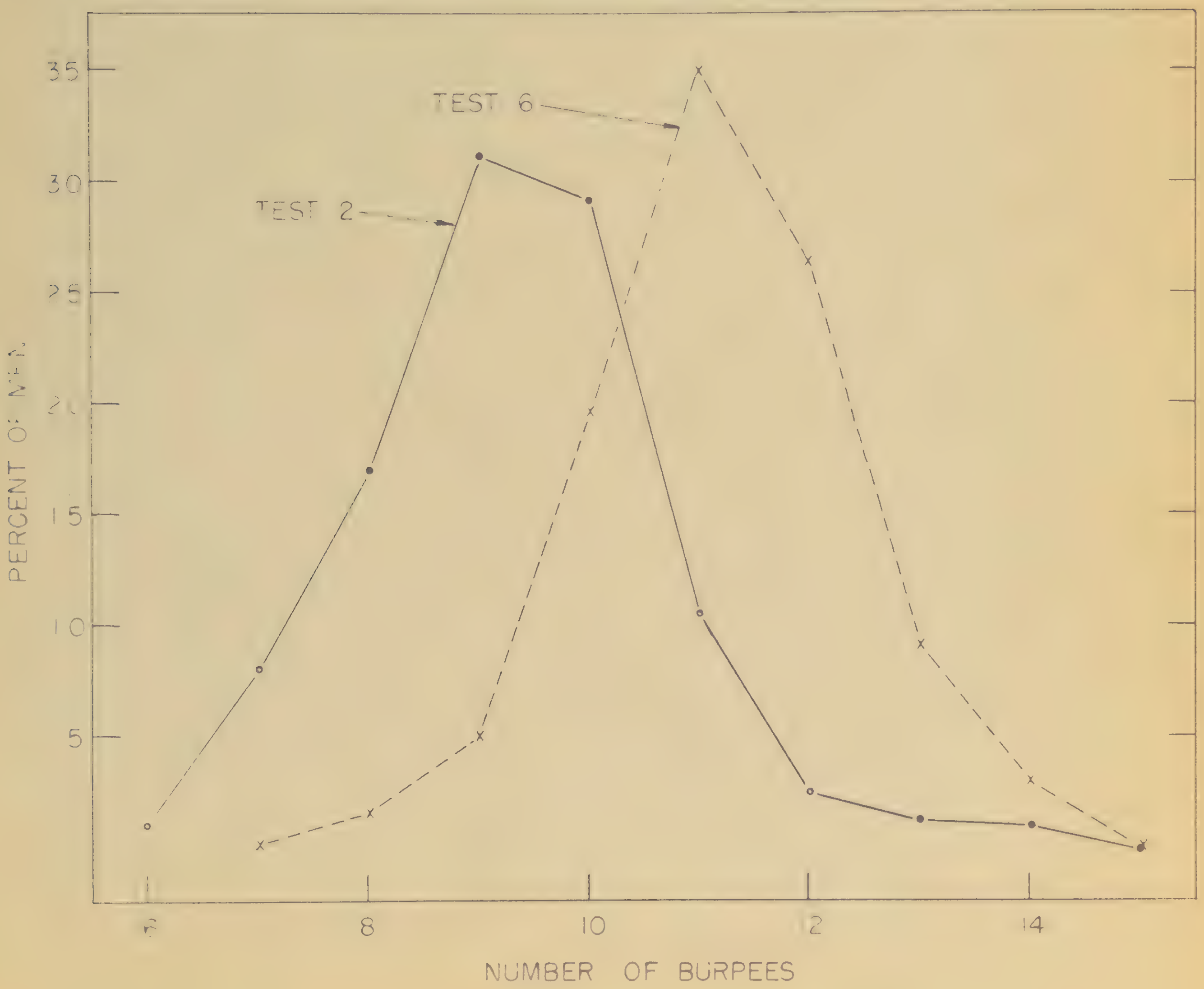


FIG 19

DISTRIBUTION OF SCORES ON AGF TEST

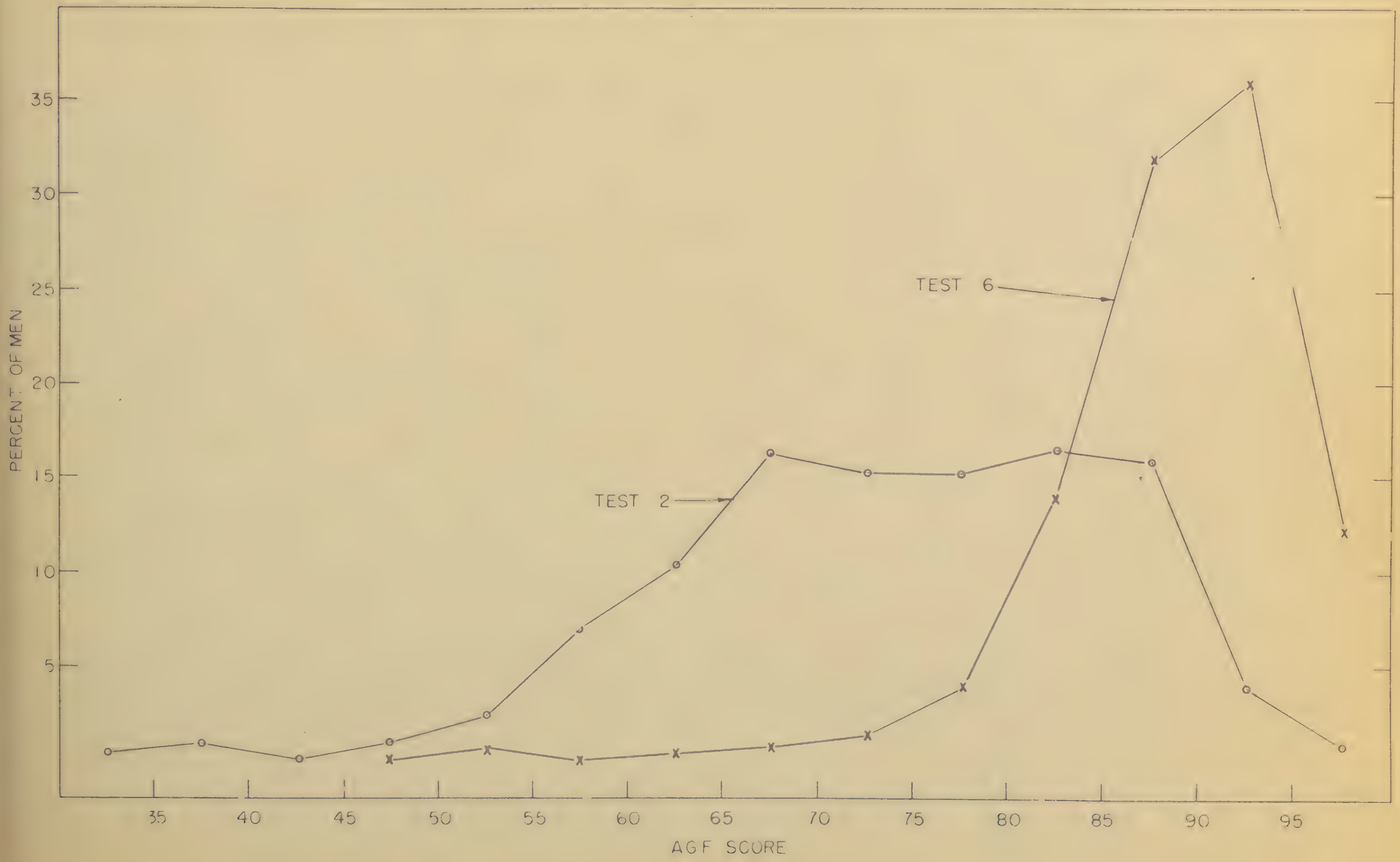


FIG. 20

THE IMPROVEMENT IN FITNESS SCORES IN EACH TEST WITH PHYSICAL CONDITIONING

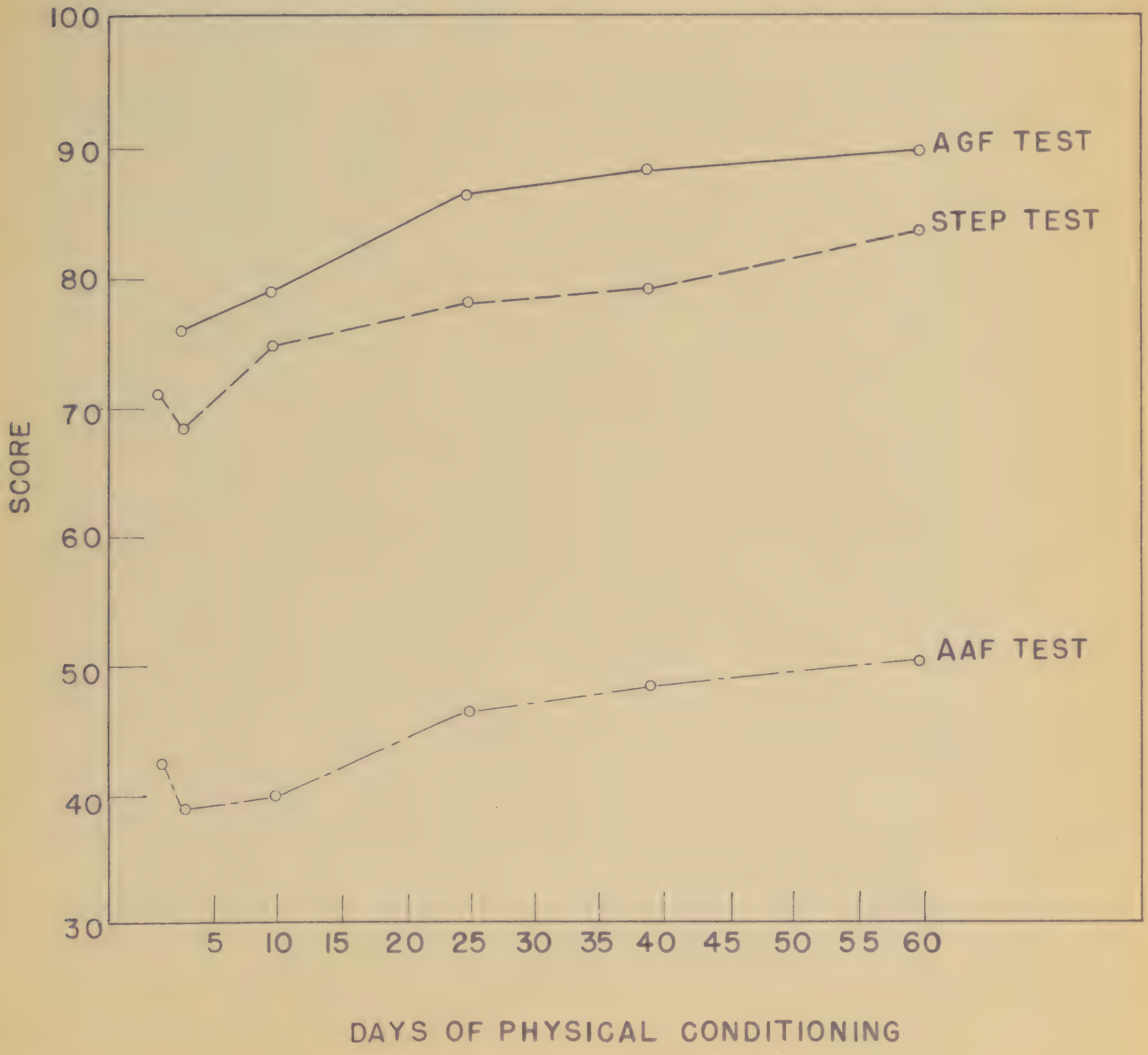
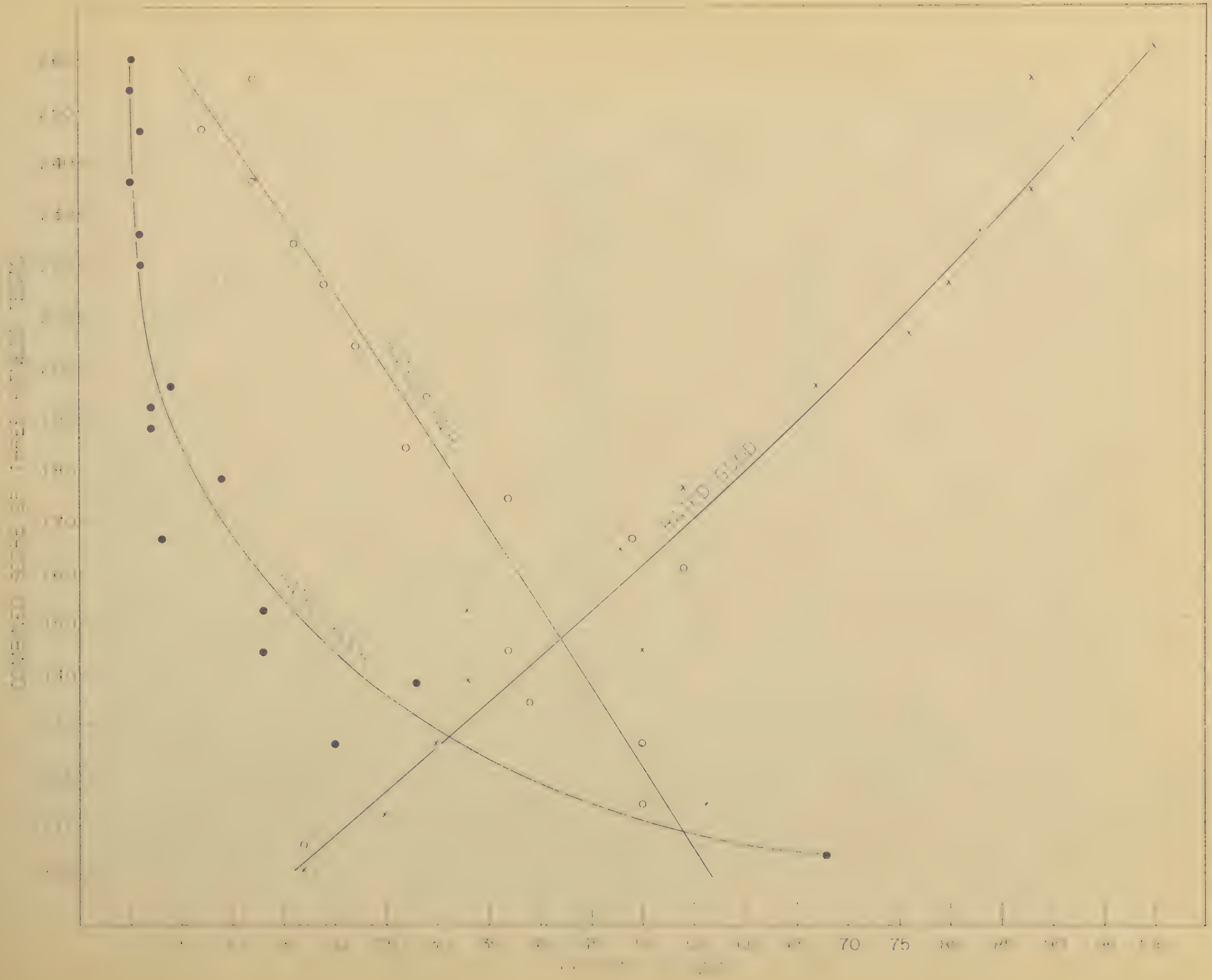


FIG 21

[illegible]

[illegible] COMPARED TO COMBINED SCORE OF [illegible]

FITNESS TESTS



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AN APPARATUS AND METHOD FOR THE CONTINUOUS MEASUREMENT OF EVAPORATIVE WATER LOSS FROM HUMAN SUBJECTS*

by

Edward D. Palmes, 1st Lt., Sn.C.

from

Armored Medical Research Laboratory
Fort Knox, Kentucky, 28 February, 1947

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*Sub-project under Studies of Body Reactions and Requirements under Varied Environmental and Climatic Conditions. (A.M.R.L.-55). Approved by CG, ASF, 31 May 1946.

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Project No. 55-1
MEDEA

28 February 1947

ABSTRACT

AN APPARATUS AND METHOD FOR THE CONTINUOUS MEASUREMENT OF EVAPORATIVE WATER LOSS FROM HUMAN SUBJECTS

OBJECT

The evaporation of water from the skin and lung surfaces is an important factor in the thermal balance of man. Methods formerly employed for the determination of evaporative rate gave only average values for relatively long intervals of time and, hence, could not be used to detect rapid changes in rate. The measurement of high sweat rates by these methods was also very difficult. It was desirable, therefore, to develop an apparatus and method which would record continuously the rate of evaporation of water from the body under a wide range of experimental conditions.

PROCEDURES AND RESULTS

An apparatus was developed which gave a continuous record of evaporative rate. The subject was placed in a chamber through which a steady flow of air at several closely controlled temperatures and humidities was maintained by an air conditioning unit. The inlet and outlet air streams of the chamber were analysed for water vapor simultaneously by a special modification of an N.D.R.C. Selective Gas Analyser, Model IV. The optical system of the analyser was altered so that one beam of infra-red radiation passed through a sample of inlet air and a parallel beam through a sample of outlet air. The difference in absorption of radiation caused an electrical imbalance in the receiving thermopile, and this was amplified and recorded as a continuous tracing.

From this record it was possible to calculate a virtually instantaneous evaporative rate or the total evaporative loss for any portion of the run. The total evaporation for the entire run was first calculated using a factor based on the flow of air through the chamber and calibration data for the analyser. This was then compared with another value for evaporative loss determined independently from the weight change of the subject. Variations of as much as ±15% were found between the results obtained by the two methods. Since the time between weighings was great, the calculations from weight change were considered to be more accurate, and the factor used for calculation of evaporative loss from the analyser record was corrected, therefore, so that it would yield the same value as that measured by the balance for the same run. The corrected factor was then used to calculate evaporative rates during the run.

The apparatus and method were applied to measurement of evaporative loss from normal and febrile subjects, at ambient temperatures from 80° to 110°F. Satisfactory results were obtained during periods of insensible water loss, of high and variable sweat rates, and of violent muscular movement.

CONCLUSIONS

1. The apparatus and method described are satisfactory for the measurement of the rate of evaporative water loss from man under a wide variety of experimental conditions.

2. The continuous and almost instantaneous record obtained furnishes more useful information than the average values for relatively long intervals yielded by other methods.

3. The technic should be applicable to problems of thermal balance of clothed and working men, and to the study of the physiological mechanisms which control the rate of water loss from the skin and lungs.

RECOMMENDATIONS

It is recommended that this apparatus and method be employed for the measurement of rate of evaporative water loss, particularly in situations where the rate changes rapidly.

Submitted by:
Edward D. Palmes, 1st Lt., Sn.C.

Approved Ray G Daggs
RAY G. DAGGS
Director of Research

Approved Frederick J Knoblauch
FREDERICK J. KNOBLAUCH
Lt. Colonel, M.C.
Commanding

AN APPARATUS AND METHOD FOR THE CONTINUOUS MEASUREMENT OF EVAPORATIVE WATER LOSS FROM HUMAN SUBJECTS

I. INTRODUCTION

A. Definition of Terms

Water will evaporate from a wet surface if the vapor pressure of the water is greater than that of the surrounding air. The rate at which this occurs, however, is not only a function of the vapor pressure gradient but also of the wetted area and the movement of air. In man, water is evaporated from the lungs and skin. The lung surface is completely wet at all times and almost completely saturates the inspired air at body temperature (1,2). The rate of evaporation varies, therefore, only with the vapor pressure of the inspired air and the air movement through the lungs, or ventilation rate. During periods when there is no active sweating, evaporation from the skin proceeds at a low rate even in the presence of a large vapor pressure gradient and high wind movement, and it must be concluded, therefore, that only a small fraction of the skin acts as a wetted surface (3). Under these conditions the liquid is not visible or tangible and evaporation is termed "insensible" water loss. When there is active secretion of sweat, on the other hand, a larger fraction of the skin surface is wetted and evaporation proceeds at a higher rate. If the water on the skin is grossly perceptible, evaporation is termed "sensible" water loss. It should be noted that these terms do not distinguish perfectly between active and passive excretion of water, because under favorable conditions of vapor pressure and air movement, water secreted by active sweating will be vaporized so rapidly as to be "insensible".

B. Importance of Problem

The loss of water by evaporation is an important factor in the study of thermal balance since each gram of water vaporized at skin temperature removes approximately 0.6 Calories of heat from the body. This cooling takes place whether the evaporative loss be sensible or insensible. From the thermal point of view, the passive loss of water in cool environments often falls in the class of necessary evils since its cooling effect is not essential to the control of body temperature. Active sweating, on the other hand, is critical to the maintenance of life since high rates of cooling must be obtained when internal heat production is great or environmental temperatures are high. Insensible water loss is the result of the diffusion or osmosis of water through the skin (4) and is, therefore, a purely physical phenomenon while active sweating is a true physiological defense mechanism. In spite of this fact, there has been a great preponderance of work done on the insensible loss of water. It is believed that the reason for this is that many difficulties are encountered in the measurement of sweat rates, and it is hoped that the apparatus and method described in this report will obviate some of these.

C. Methods Previously Employed

1. Direct Method

The rate of evaporation of water from the skin and lung surfaces has been determined by direct measurement of the water vapor liberated. Two methods have been employed for this purpose.

a. The first of these depends on the absorption of the vapor in a desiccant, and measurement of the amount of water liberated by determining the weight change of the desiccant. A well known example of this method of measurement is found in the Atwater-Rosa-Benedict respiration calorimeter reported in 1915 by Lusk (5) and Riche and Soderstrom (6). The calorimeter contains a closed circuit system including a bubbler filled with sulfuric acid which acts as an absorbent for the water vapor liberated. The bubbler is removed and weighed at intervals of 20 minutes to one hour and an average rate of evaporative loss for these periods obtained. This method is not adaptable to measurement of rapid changes in evaporative rate, since the large number of weighings necessary would not be technically practical. A further difficulty is encountered when sweating subjects are studied; there is a tendency to saturate the air of the calorimeter when evaporation exceeds 35-40 gm/hr. indicating failure of the absorbent to remove completely this quantity of water vapor.

b. The second method which has been used for the direct measurement of water vapor loss is similar in principle to the one proposed in this report. The subject is sealed in a casket from which only the head protrudes; a known stream of air is passed through the casket; and the relative humidities of inflowing and outflowing air are determined by hair hygrometers. Evaporation from the skin within the casket is calculated from the flow and the change in relative humidity of the air. Von Willebrand (7) in 1902 reported such an apparatus and stated that 15 to 20 minutes were required from the time the subject was sealed in the casket until the outflow hygrometer reached equilibrium. The device was used only for measurement of insensible loss. Schwenkenbecher (8) in 1904 used the same method and found that 20 to 30 minutes elapsed before the outflow hygrometer reached a stable value. The author calibrated the instrument by spraying water into the casket at a known rate, and reported maximum errors of about 8%. Unfortunately, neither the details of the experiment nor the calculations were given. Using the same apparatus, Schwenkenbecher and Inagaki (9) in 1905 measured insensible loss and some low sweat rates. Moog and Nauch (10) in 1921 and Schluter (11) in 1925 used Schwenkenbecher's casket for determination of insensible water loss. No mention of method of calibration or calculation were contained in these articles. From these reports, it appears that the hair hygrometers have too long a response time for measurement of rapid changes in evaporative rate and that more data on the accuracy of the instrument are to be desired.

2. Indirect Method

The rate of evaporative loss has also been measured indirectly by determining the weight change of the subject. The total weight loss

must be corrected for food and water ingested, urine and feces excreted and the excess weight of CO_2 eliminated over O_2 absorbed (CO_2 excess). Sanctorius (12) in 1614 measured his own weight change when no active sweating was taking place and coined the term "insensible perspiration" for the observed weight loss. Insensible perspiration has been measured extensively since Sanctorius' time, and the methods and apparatus employed have been well reviewed by Kuno (13). This is not a true measure of water loss, since no correction of the weight change for CO_2 excess is made.

All the necessary corrections have been applied to weight change by some investigators to obtain a true value for evaporative loss. At the Pierce Laboratory Winslow, Herrington, and Gagge (14,15,16) employed a scale sensitive to 2 gm for measuring evaporation from resting and working subjects over a wide range of environmental conditions. Weights were taken at intervals of 15 to 30 minutes in these studies and average evaporative rates were calculated. The work pattern of the subject was interrupted for the weighings, and due to the length of the intervals, rapid changes in evaporative rate could not be measured.

Nielsen (17) in 1938 reported a method in which the subject worked on a bicycle ergometer suspended from the arm of a balance which was sensitive to 2 grams. The movement of the subject as well as his loss of weight produced balance deflections which were recorded on a kymograph. The deflections were, of course, superimposed one on the other, but it was possible to determine an average slope which was attributable to weight loss alone. The accuracy of the calculation depended on the smoothness with which the subject operated the ergometer and the author states that wind blowing on the subject also interfered with the measurements.

The fact that air movement interferes with balance readings is a serious consideration when high sweat rates are to be measured. Only that portion of the sweat which is evaporated is useful in cooling the body, and application of an accurate correction for sweat which drips from the subject is impossible in practice. Complete evaporation of large amounts of sweat, on the other hand, usually requires rapid air movement. At this laboratory, Eichna, Ashe, Bean and Shelley (18) in 1945, Shelley, Eichna and Horvath (19) and Horvath and Shelley (20) in 1946 measured sweat rates of men working at high ambient temperatures by determining weight loss. To insure complete evaporation of sweat, rapid movement of air was maintained in the test room; but it was necessary to remove the subjects from the windy environment to the still air of a control room or a booth for weighings. Total evaporation for experiments lasting several hours was determined. In later work an attempt was made to measure weight loss of working men at shorter intervals by Eichna, et al (21). It was necessary to employ the weighing booth in this study also, and the work pattern of the subject had to be interrupted for each weighing. The difficulty encountered in measurement of evaporative rate in these studies was the prime reason for the investigation described herein.

II. EXPERIMENTAL

A. Apparatus

1. Experimental Chamber and Ventilating System

a. Description

The subject was enclosed in a ventilated chamber, shown schematically at the top of figure 1, the overall inside dimensions of which were 3 x 3 x 8 feet excluding the small pyramidal section on the right end. The box had a large door, and tubes from a respiratory metabolic apparatus passed through the walls. The subject reclined on a waterproofed netting stretched across the center of the man compartment.

For ventilation of the box, air from outside the building was drawn into an air conditioning unit where it was cooled and saturated with water vapor in a water spray tower kept at 4°C. Since the vapor pressure of water at this temperature is 6.1 mm.Hg., the air contained about 1% water vapor. It was then pumped through a steam-heated heat exchanger, where it was warmed to the desired temperature, and thence into the 2 inch pipe and diffusion compartment both shown at the top left of figure 1. The diffusion compartment comprised a six inch section of the box and was separated from the man compartment by a wooden grill (indicated by the broken line) the interstices of which were loosely packed with coarse hair felt. This baffle served to break up the air stream from the inlet pipe and thus produced a uniformly distributed flow into the man compartment. A variable speed fan mixed the air so that a representative sample would be obtained from the outlet pipe.

b. Determination of Flow through the Box

Air was pumped to the box by a Victor-Acme blower* which delivered a practically constant weight of air regardless of small fluctuations in back pressure. Flow was determined by shunting the air from the inlet pipe to a large spirometer (capacity 500 liters) for an accurately timed interval. The volume of air in liters delivered per unit time was corrected to standard conditions and the value divided by 22.4 to give the moles of gas per unit time. These values ranged from 65.9 to 67.7 moles per minute, with an average of 66.9 moles per minute. The orifice flowmeter, a 1.38 inch plate orifice in the 2 inch inlet pipe was used to determine constancy of flow and not for absolute values. The manometers were read each 15 minutes during the man runs, and variations in both static and differential heads were very small.

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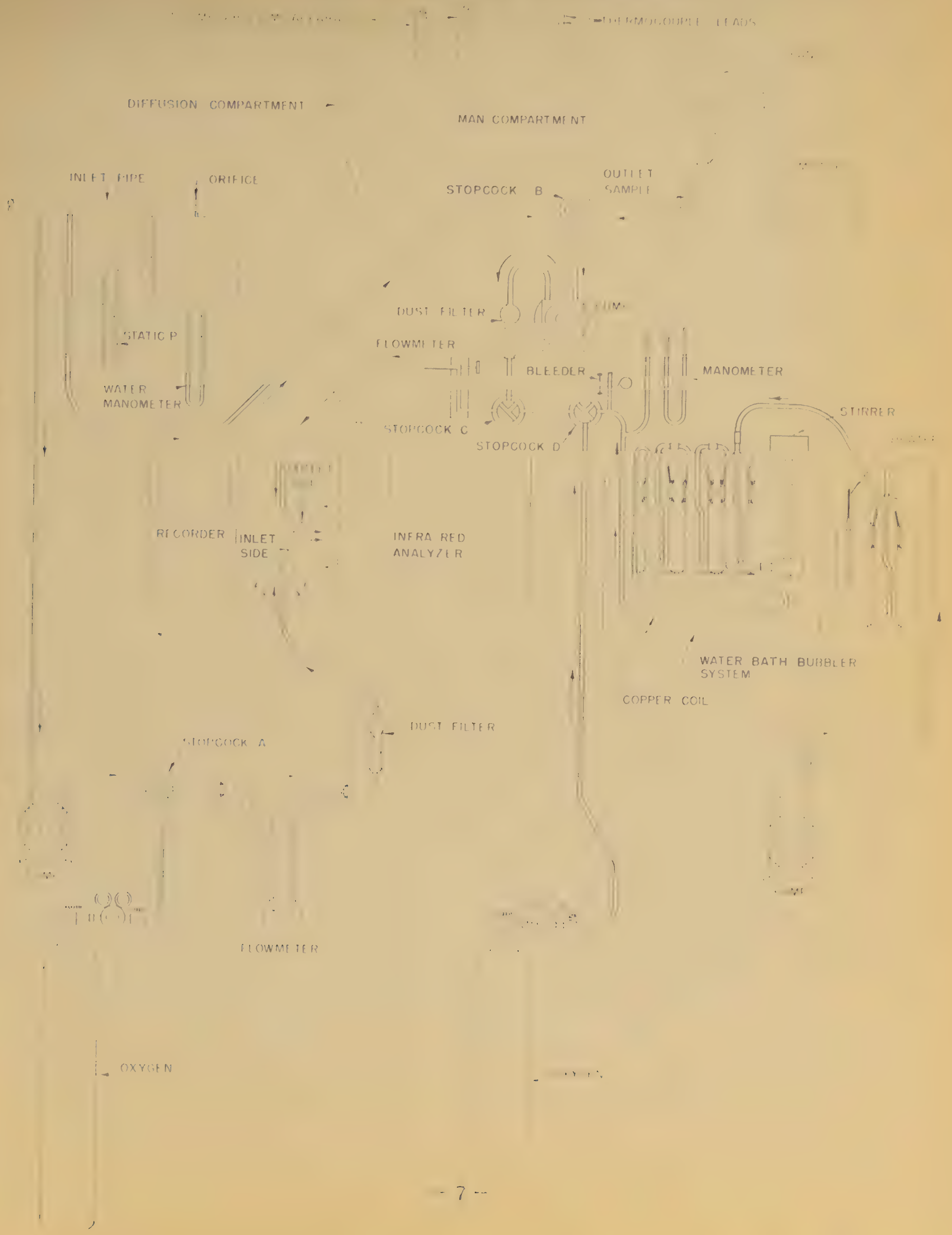
* Manufactured by the Root-Connersville Blower Corp., Connersville, Indiana.

FIGURE I
SCHEMATIC DIAGRAM OF APPARATUS



c. Rate of Substitution of Air in the Box

Assuming perfect mixing in the box, the rate of substitution of inlet air for that contained in the box was expressed by the formula:

$$\log X = -0.4343 \frac{F}{V} t$$

where X = fraction original air remaining
F = flow into the box in moles/minute
V = volume of box in moles
t = time in minutes

The volume of the box was 78 moles (100°F and 760 mm.) and the flow 66.9 moles. Hence, the per cent of original air remaining after 1, 2, and 3 minutes was 42, 18, and 8 respectively.

2. The Infra-Red Gas Analyser

a. Background

An N.D.R.C. Selective Gas Analyser, Model IV, specially modified at this laboratory, was used for the measurement of the difference in concentration of water vapor in the air entering and leaving the chamber. The original apparatus was designed by Fastie and Pfund (22) and the final instrumentation was carried out at the Leeds and Northrup Company.

The machine records continuously the concentration of various gases having strong absorption bands in the near infra-red region of the spectrum and proved very useful for the determination of air contamination by these gases since O_2 and N_2 show a negligible absorption in this region. A report by Fastie and Peters (23) gives a brief review of the applications of the apparatus to determination of air contamination by CO, CO_2 and HCN.

These workers also applied the original apparatus to the measurement of water vapor concentration, but were unable to obtain sufficient sensitivity. They made certain modifications in the analyser and, in pilot experiments, showed that the sensitivity could be greatly improved. Due to the unavailability of the report during the time when the present study was in progress, the machine was modified independently at this laboratory along other lines and with quite different end results.

The measuring cell assembly of the analyser is the only portion which will be considered in detail, since it is in this unit that absorption of infra-red radiation by the test gas produces an electrical signal which is proportional to the concentration of this gas. Other components of the analyser are used for amplification and recording of this signal.

b. The Measuring Cell Assembly

The construction of the measuring cell assembly is shown by the cross sectional drawing in figure 2A. The drawing is to scale and the overall height of the assembly is approximately 12 inches.

At the top is a housing containing the infra-red source, an electrically heated nichrome coil (A). The radiation from this source passes through the intermediate parts of the optical system. The beam is split in the cone (H) so that one half strikes each of the sets of junctions (I and I') of a differential thermopile.

The remainder of the assembly consists of windows (B and C), analysis cell (D), compensator (E), selectivity adjustment device (F), and cone (H). A top view of the selectivity adjustment device (F) is shown in the center of the figure so that the two blackened metal rods (G) may be seen.

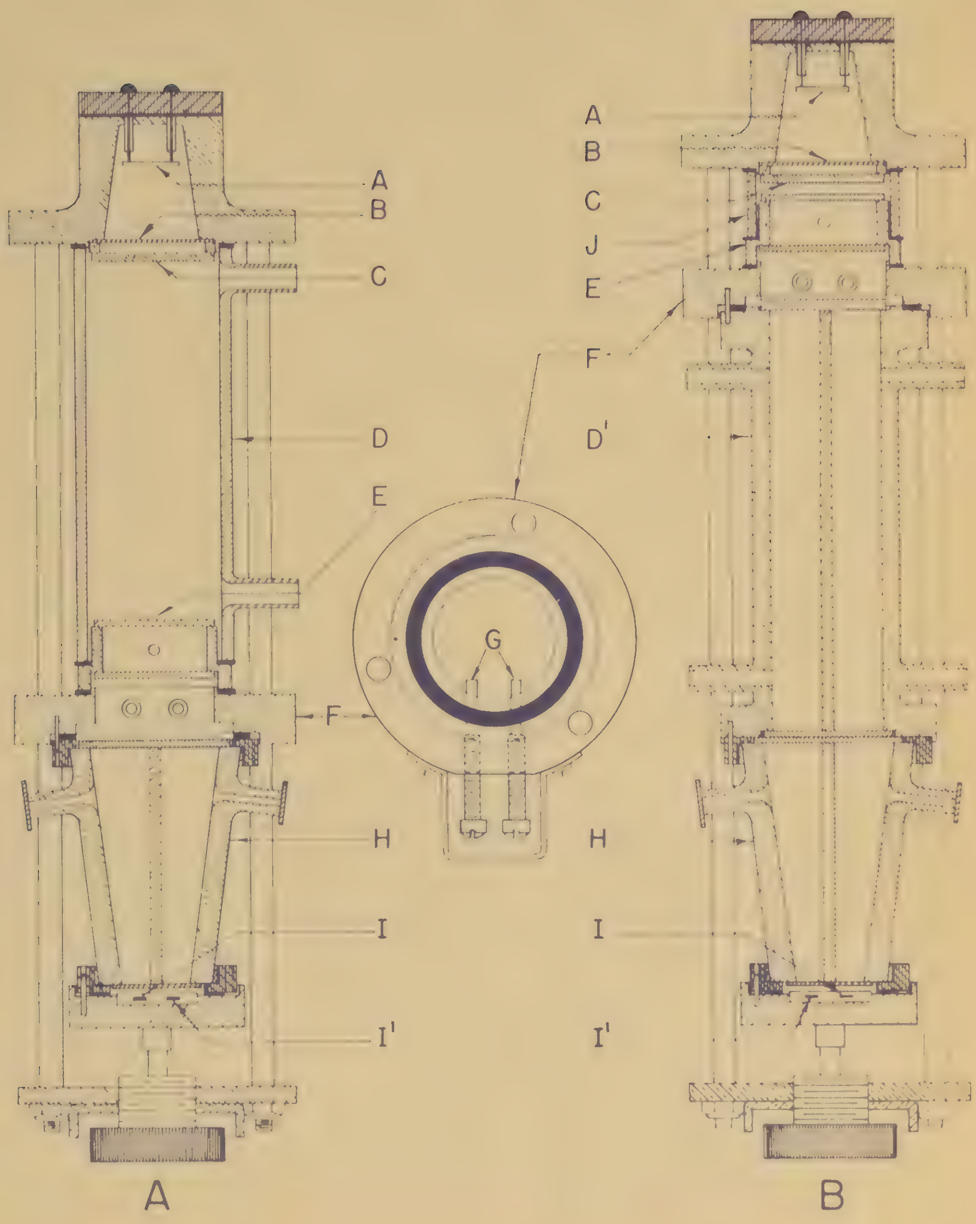
Window (B) is made of mica, and the remainder of the windows in the system are of lithium fluoride, which has a very high transmission in the near infra-red. The inner surfaces of the assembly are gold plated to reduce absorption of radiation by the walls.

c. Operation

As is shown in the figure, the optical system is symmetrical, hence, if there is no absorbing gas in any of the parts the intensity of radiation striking each side of the thermopile is the same. If a particular gas having strong absorption bands in the infra-red is to be determined, the left side of the cone is filled with this gas. Thus, the amount of radiation falling on the thermal junctions (I) is reduced. The right side is filled with a non-absorbing gas, such as oxygen, and essentially all the incident radiation is transmitted through this side of the cone to the other set of junctions (I'). The thermal unbalance produced by the difference in absorption of the two gases produces an unbalance in electrical potential. While passing oxygen through the analysis cell (D), the system is brought back into electrical equilibrium by application of an external bucking potential in the thermopile circuit. When this is done the assembly is prepared for the actual measurement of the test gas. A stream of air, containing a low concentration of this gas, is allowed to flow through the analysis cell. The presence of the test gas will now markedly reduce the radiation transmitted to I', but will have virtually no effect on that reaching I since most of the absorbable radiation has already been removed by the gas in the left side of the cone. Thus the potential on the right side will be reduced; that on the left side will remain the same; but the bucking potential as originally adjusted will no longer balance the thermopile circuit. The degree of unbalance will vary according to the concentration of gas flowing through the analysis cell and it is this unbalance which constitutes the electrical signal that is subsequently amplified and recorded.

FIGURE 2

MEASURING CELL ASSEMBLIES



The function of the compensator (E) is to minimize the interference of a contaminating gas which has infra-red absorption bands overlapping those of the gas to be measured. The compensator is filled with the contaminating gas, and the portion of the radiation absorbable by this gas is thus removed from both sides to a large extent. If minor deflections are still obtained when the contaminant is introduced into the analysis cell the selectivity adjustment device (F) can be reset by extending one of the rods (G) into the beam, thus changing the spectral response of the thermopile.

d. Amplifier and Recorder

The potential difference between the two sides of the thermopile circuit is amplified by a D.C. chopper-type amplifier and the resultant signal recorded on an Esterline-Angus recording milliammeter. Thus, when the two sides are first balanced by adjustment of the backing potential, the recorder pen will rest on the mechanical zero point of the meter. If subsequently there is an unequal change in the potentials developed by the two sides of the thermopile, a corresponding deflection will be produced on the recorder.

The amplifier gain can be adjusted so that full scale deflections on the recorder are obtained with net potential changes of 25, 100, or 200 microvolts in the thermopile.

A continuous record of deflection is made on a tape which is moved at constant rate under the writing pen of the meter.

e. Adaptation of the Analyser to the Measurement of the Concentration of Water Vapor in Air

It was necessary for the analyser to have a high degree of sensitivity to small changes in concentration of water vapor, since it was desirable to maintain a large flow of air through the chamber. A large flow was essential for the complete evaporation of water from the subject and for rapid detection of changes in evaporative rate. Specificity of the instrument on the other hand, was not a critical factor, since the only contaminant which might be encountered was the CO_2 excreted by the man. The compensator (E) was filled with CO_2, therefore, and even relatively high concentrations of this gas had no effect on the determination of water vapor.

Although water vapor has strong absorption bands in the infra-red, it was necessary to have a high concentration in one side of the cone to obtain the necessary sensitivity. Preliminary tests, in which the

cone was filled with O_2 saturated at room temperature, showed a very low sensitivity.* In order to increase the concentration of water vapor in the cone, it was necessary to raise the temperature of the entire measuring cell assembly.** The unit was, therefore, placed in a thermostated air bath at 50°C and the cone filled with O_2 saturated at 48°C. On the first calibration satisfactory sensitivity was demonstrated, but this decreased progressively on subsequent days. The decline was attributed either to leakage from the cone or to absorption of the confined water vapor by the windows. In any case, attempts to prevent the loss were unsuccessful and the assembly was, therefore, modified.

The final modification of the assembly is shown in figure 2B. The compensator (E) and selectivity adjustment device (F) were shifted to positions nearer the infra-red source (A) and a brass sleeve (J) was used to hold the compensator in place. The segment (D') was a brass tube divided into two equal compartments by a septum and sealed on both ends by lithium fluoride windows. The inside of the tube and the septum were gold plated, and two side-arms were provided for circulation of gas through each cell. Both sides of the cone (H) were filled with O_2, and this unit served only as thermal insulation*** between the circulating gases and the thermopile (I and I').

When samples of the same gas were passed through each compartment of the unit (D') the absorption of radiation on each side was equal. The bucking potential was adjusted under this condition so that a zero output from the thermopile circuit was obtained. Next, while maintaining the flow of the original gas through one compartment, a second gas was passed through the other. If the absorption by this gas were different from that of the first, a deflection was produced on the recorder. Thus, one gas was always compared against another, and the difference in absorption recorded. In this system the specificity of the original apparatus was lost, since any infra-red absorbing gas would be measured. When the apparatus was used in conjunction with the ventilated box for the measurement of evaporative water loss, however, the only interfering gas was CO_2, and this had a negligible influence in the concentrations produced by the subject.

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* Fastie and Peters (23) obtained similar results, but when CaF_2 windows were substituted for those of LiF a great increase in sensitivity was obtained. This was attributed to greater transmission by CaF_2 of radiation absorbable by water vapor. The response to water vapor reported by them was roughly half of that obtained at this laboratory using the finally modified measuring cell assembly, and no data on reproducibility were given.

** This procedure was suggested, but not tried, by Fastie and Peters (23).

*** In a previously tested assembly, a single continuous unit took the place of the segment (D') and the cone (H). Thus the circulating gases were separated from the thermopile only by a thin window and a very small air space at the bottom of the unit. The apparatus was found to be extremely sensitive to small fluctuations in the temperatures of the test gases, and was quite unstable.

B. Methods

1. Calibration

a. For calibration, a water free gas was circulated through one compartment of the unit (D') while air of known water vapor concentration was passed through the other. The proper degree of humidity was obtained by saturating air at a measured temperature and pressure; the water bath-bubbler system shown at the right side of figure 1 was used for this purpose. Sintered glass bubblers filled with distilled water were immersed in water baths whose temperatures could be closely regulated. Air was first pumped through a single bubbler contained in a bath kept at 50°C; here it was strongly humidified. It then passed through a series of three bubblers and a 10 foot copper coil immersed in a second bath which was kept at a temperature between 2° and $17^{\circ}C$. The copper tube served as a trap for any water splashed out of the last bubbler and for the final thermal equilibration of the air with the bath. The temperature of the bath was measured with a mercury thermometer and that of the air leaving the tube with a thermocouple. Since the agreement between the two readings was very close, the air could be considered saturated at the bath temperature; and, hence, had a known vapor pressure. Total pressure was obtained by adding the static head, measured by the manometer, to atmospheric pressure. Concentration of water vapor in moles per cent could be calculated from the equation:

$$\frac{\text{Vapor pressure}}{\text{Total pressure}} \times 100 = \text{moles per cent water vapor}$$

If the temperature of the air were subsequently raised or its pressure lowered, there would be no change in composition.

b. Dried air was tried as a reference gas in preliminary work, but this required the use of a desiccant whose life was necessarily limited. Commercial oxygen was subsequently employed, therefore, since it was a much more convenient and constant source of water free gas.

c. Oxygen was continuously supplied to one analysis chamber by setting stopcock A of figure 1, and either oxygen or air of known water vapor content could be passed through the other by adjustment of stopcocks C and D. A flow of approximately 10 liters per minute was maintained through each side. While circulating oxygen through both chambers, the output from the thermopile circuit was adjusted to zero and the recorder registered no deflection. Moist air was then substituted for oxygen on one side for a period of 1-2 minutes, at the end of this time oxygen was again compared against oxygen to reestablish the base line. Sample calibration tracings are shown in figure 3A. Any drift in the zero value was assumed to be linear and the deflection was measured from the interpolated base line (broken line of figure 3A). All of the tracings in this figure are read from right to left.

d. It was found that the response of the analyser to the same concentration of water vapor was not constant from day to day. This is shown by the scatter of the points in figure 4. On a single calibration run,

FIGURE 3
SAMPLE TRACINGS

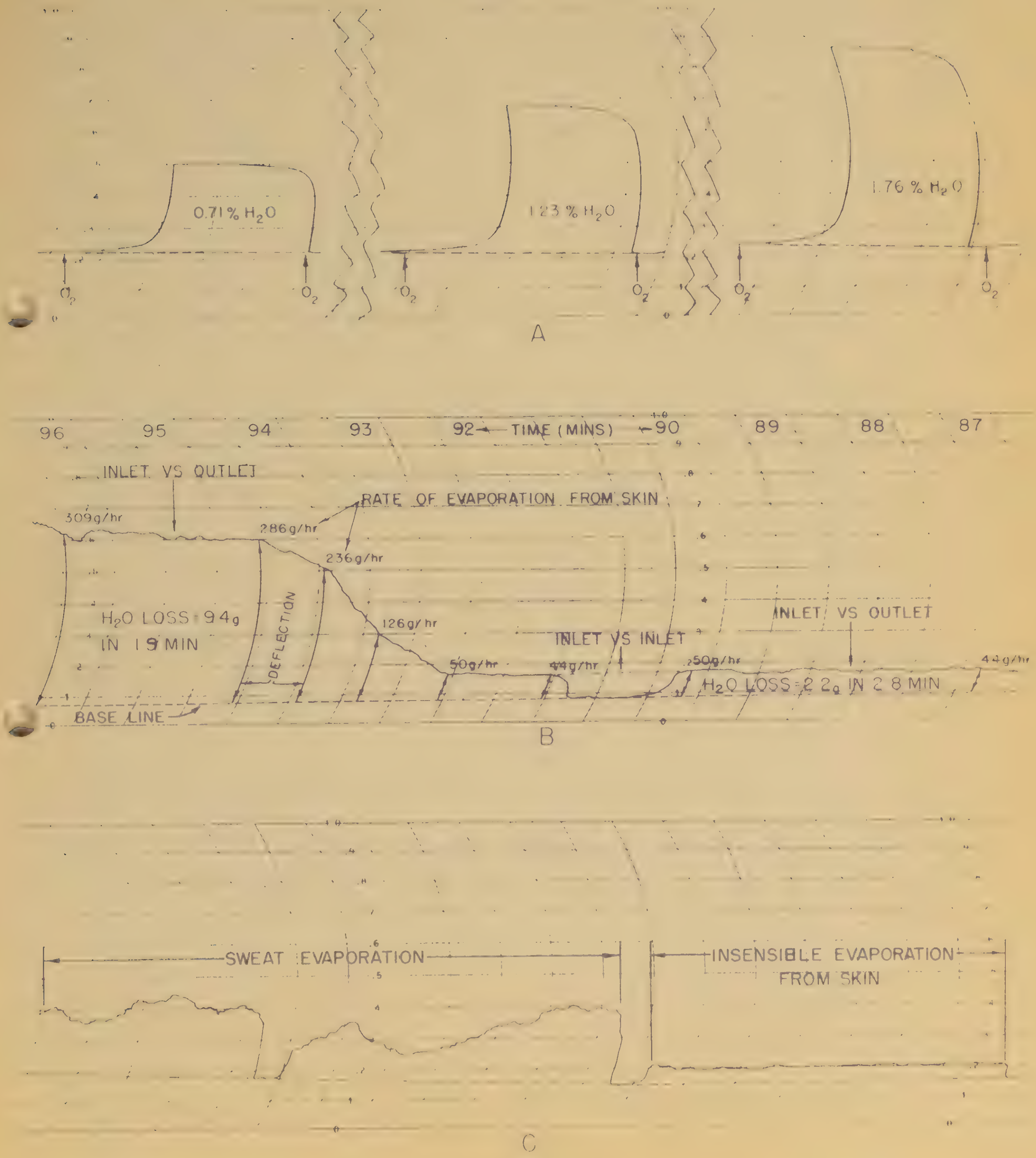
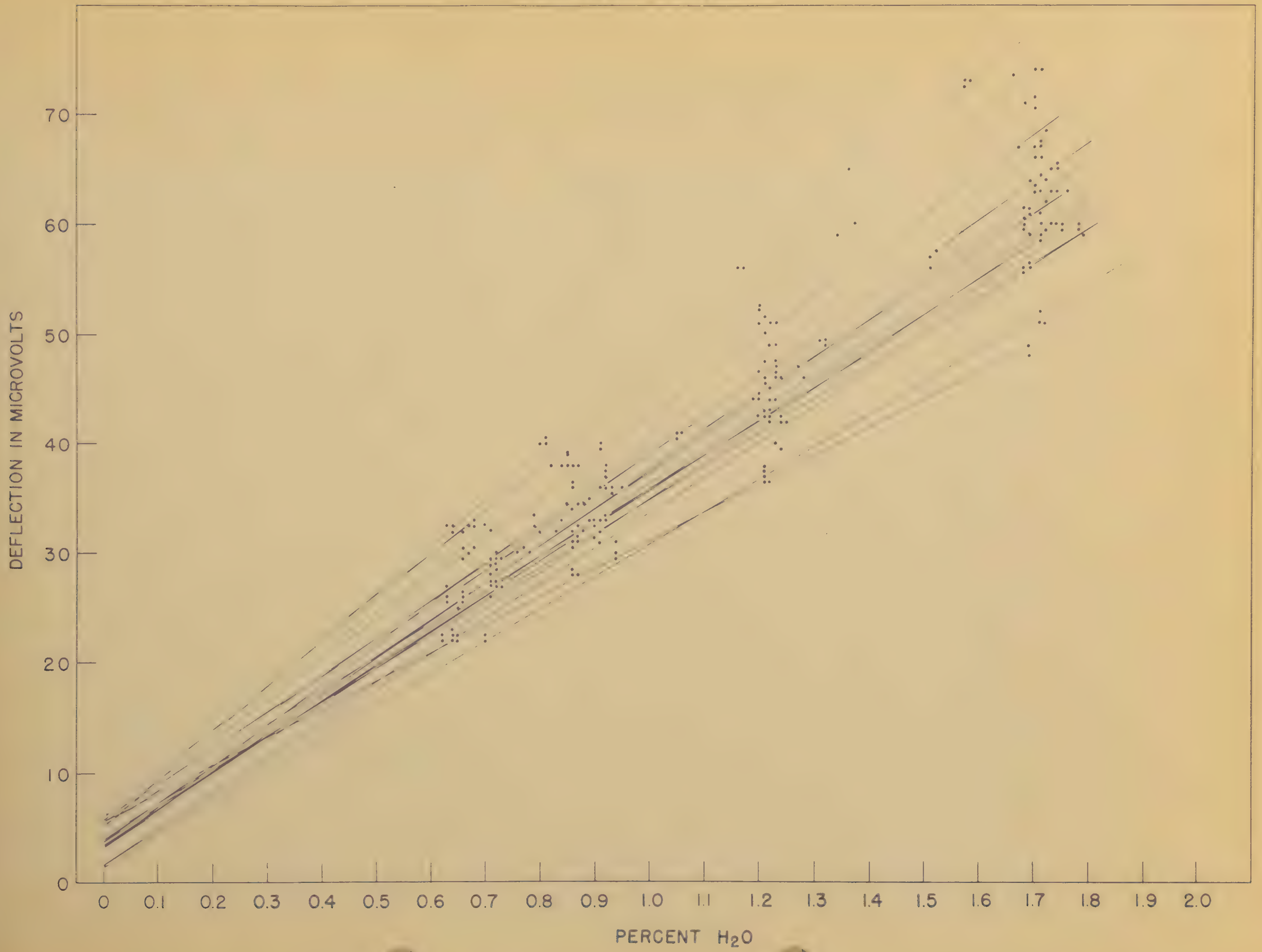


FIGURE 4
CALIBRATION CURVES



however, the points obtained by measuring the deflections produced by four different concentrations fell very close to a straight line; the actual deviations are summarized in table 1.

TABLE 1

Summary of Deviations from a Straight Line of Points Obtained on Single Calibrations

Range of Deviation (Microvolts)	Number of Values In Range	Per Cent
0.0 to 0.5	169	63
0.5 to 1.0	65	24
1.0 to 1.5	19	7
1.5 to 2.0	17	6

The curves obtained on 23 such calibrations are also indicated in figure 4, and it is seen that the slopes are fairly constant. The average slope of all curves was 34.8 microvolts per one per cent water vapor in the range of 0.7 to 1.7%. Seventy-four per cent varied from the average by 5% or less and the extreme variations were about 20%.

It would have been possible, by using this data, to determine the difference in the concentrations of water vapor in the air at the inlet and outlet of the chamber by alternately comparing each against oxygen. It was much more convenient, however, to compare the two gases against each other directly. Hence, an experiment was undertaken to test the validity of this procedure. The inlet air gave a constant deflection over long periods when measured against oxygen and the same was true of air from the water bath-bubbler system when the temperature of the bath was held constant. Thus, the difference in deflection between the two gases was calculated when each was compared against dry oxygen, and these values were plotted against others obtained by determining directly the deflection produced when one moist gas was measured against the other; the results are shown in figure 5. The line is the locus of points which would be in perfect agreement. The deviations from the line were sufficiently small that the method of comparison of the two gases directly was considered satisfactory, and was adopted for all experiments.

e. During the calibration runs it was possible to ascertain the response time of the machine to an almost instantaneous change in water vapor content of air on one side of the analysis cell. Repeated observations indicated that the response was maximum within one minute and that it was 95% of maximum in 15 seconds.

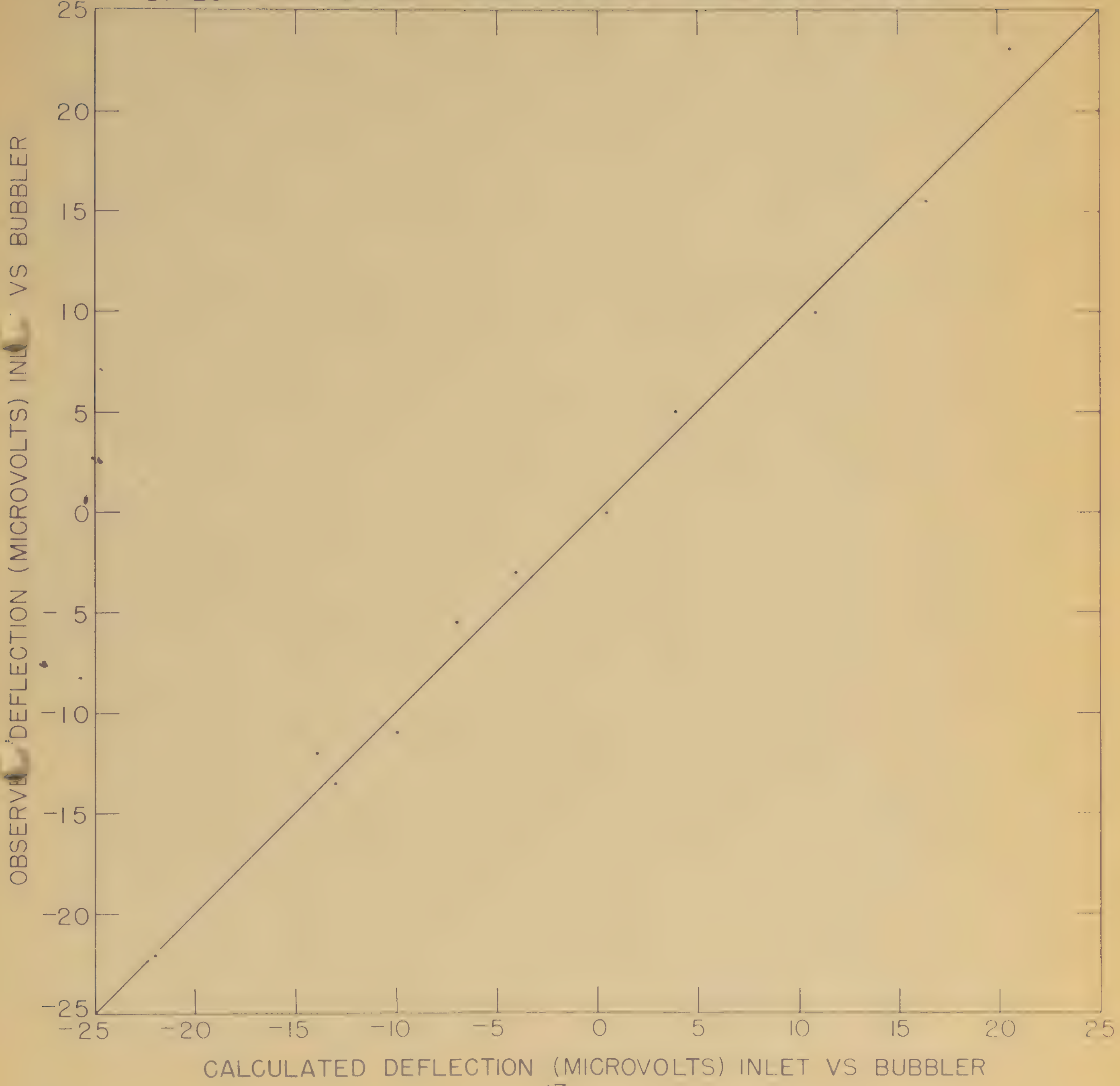
2. Calculations

a. Evaporative Rates

The rate of evaporation occurring within the box at any instant could be calculated by multiplying the flow rate by the difference in concentration of water vapor in the inlet and outlet air. To simplify

FIGURE 5

DIRECT VS INDIRECT COMPARISON OF TWO MOIST GASES



this calculation, a factor was derived for the direct conversion of deflection to evaporative rate. All units in these and subsequent calculations are: moles for quantities, moles/moles for concentrations, and moles per minute for flow rates, except as otherwise indicated.

The evaporative rate was equal to the difference between the flow of water vapor to and from the box, or:

(1) $H = H_L - H_E$

where H = rate of evaporation

H_L = flow of water vapor from the box

and H_E = flow of water vapor to the box

The flow of water vapor was a function of the total flow of air and the concentration of water vapor, or

(2) $H_E = [H_E] F_E$

where $[H_E]$ = mole fraction water vapor of inlet air,

and F_E = flow of air into the box,

Similarly,

$H_L = [H_L] F_L$

where $[H_L]$ = mole fraction water vapor in outlet air,

and F_L = flow of air out of the box.

Thus,

(3) $H = [H_L]F_L - [H_E]F_E$

For the most rigorous treatment, the flow F_L should be corrected to F_E since only F_E is known. The difference between the two factors in any experiment was never greater than one per cent, hence the outlet flow was considered to be equal to the inlet, and equation (3) became,

(4) $H = F_E\left([H_L] - [H_E]\right)$

It was shown in the section on calibrations that the deflection obtained was a linear function of the differences in concentrations. Thus equation (4) was rewritten:

(5) $H = F_E KD$

where D = deflection in microvolts

and K = difference in concentration per microvolt.

Substituting in equation (5) the values determined for F_E (66.9 moles per minute) and K (34.8 microvolts per 1% water vapor).

$$(6)\quad H = 66.9\,\frac{0.01}{34.8}\,D$$

$$= 0.0192\ D \text{ (moles water per minute)}$$

$$= 0.346\ D \text{ (gm. water per minute)}$$

$$= 20.8\ D \text{ (gm. water per hour)}$$

b. Weight of Water Evaporated

The quantity of water vaporized in the box during a given interval was determined by integration of the analyser record, i.e. the area included between the base line and the deflection line was determined. Deflection was measured along the arc described by the recorder pen at each major inflection. Minor inflections were ignored and the tracing was thus considered as a series of straight lines. Since the arcs along which deflections were measured were constant, they could be considered as parallel straight lines. The geometric figure bounded by the tracing, the interpolated base line and two adjacent arcs could be considered as a trapezoid, the area of which is equal to the base multiplied by the average height. Deflections were converted to evaporative rates and the average value between successive readings was multiplied by the corresponding time to give the quantity of evaporative loss for the period. By simple addition, the total loss for any number of periods was obtained. A calculating machine was used for computing total loss for long periods, and it was possible to integrate the record of a 6-8 hour run in 30 minutes or less.

The method of calculation was checked by evaporation of known amounts of water within the box. A syringe containing water was weighed and placed in the box alongside a heated pan. The door was then closed and air passed through until a zero deflection was obtained when outlet was compared against inlet air. The operator then put his hand into a rubber glove sealed to a hole in the door and ejected the water from the syringe into the pan. The entire sample was evaporated and the experiment continued until a zero deflection was again obtained. The weight of water evaporated was determined by reweighing the syringe, and the analyser record obtained was integrated; the results are compared in table 2.

TABLE 2

Results of Experiments in which the Quantity of Water Evaporated was Determined by Weight Change and by Integration of the Analyser Records

Experiment No.	Total H_2O Evaporated (grams)		Calculated/weighed (Per Cent)
	Weighed	Calculated	
1	16.4	16.5	101
2	16.1	15.9	99
3	15.9	14.0	88
4	17.4	15.6	90
5	18.2	14.5	80
Average	16.8	15.3	91

The recoveries showed that the method of calculation gave values in the proper order of magnitude, but were, nevertheless, low and variable. These discrepancies will be discussed in the next section.

C. Application of Apparatus and Method to the Measurement of Evaporative Water Loss from Human Subjects

1. General

In the experiments to be reported, only the water evaporated from the skin was determined by means of the apparatus and method described. The reason for this was that it was also desirable to measure metabolism continuously, which made it necessary for the subject to breathe air from outside the box, i.e. from a metabolic apparatus. Thus, lung evaporation was not measured directly, but it could be calculated independently.

Skin evaporation was also calculated by correcting weight loss by the subject during the entire experiment for water ingested, urine excreted, CO_2 excess and lung evaporation. Since the tests usually lasted from 4 to 8 hours, the value computed from weight loss was considered more accurate. Skin evaporation calculated by integration of the record was, therefore, corrected to that computed from weight loss by using a different sensitivity factor for the analyser for each experiment. This corrected factor was used to convert deflections obtained during the test to evaporative rates.

2. Procedure

Preliminary to the actual experiment, the analyser was warmed up, electrical adjustments made, and the amplifier gain set to its maximum value (25 microvolts full scale). The flow of air through the box was started and inlet air passed through both analysis chambers until a small zero drift on the recorder was obtained. The nude subject was weighed to 15 gm., entered the box, and was connected to the metabolism apparatus. The door was closed and outlet compared against inlet air. This comparison was interrupted for one minute during each 15 minutes for the remainder of the test, and during these intervals, inlet air was circulated through both chambers of the analyser to reestablish the base line. Water ingested and urine excreted during the run were measured, and at the end of the experiment the subject was weighed again.

3. Calculation of Evaporation by Integration of the Analyser Record.

The quantity of water vaporized into the air of the box during the run was calculated by integration of the entire record using the factor 20.8 gm. H_2O per hour per microvolt deflection.

In order to compare the results with those obtained by measuring weight loss, it was necessary to extrapolate the record to the times of the initial and final weighings. A true evaporative rate was not obtained until about three minutes after the door of the box was closed, since this period was required to flush room air out of the man compartment. Hence the

first rate considered to be significant was applied to calculation of evaporative loss during the period between the initial weighing and the time this rate was taken. Similarly, the final rate obtained before the subject left the box was used to calculate a like value at the end of the experiment. When the continuity of the tracing was broken for any other reason, an interpolated rate was obtained for the period by averaging the rates measured immediately before and after the interruption. The results calculated for skin evaporation (E_S) are listed in column 9 of table 3.

4. Calculation of Evaporation from Weight Loss

Weight loss was converted to evaporative loss by correcting for water ingested, urine excreted and CO_2 excess (X). The last factor was calculated in the usual manner employing a simplified formula:

$$X = 117.9\ M\ (R.Q. - 0.727)\ t$$

When $X = CO_2$ eliminated $- O_2$ absorbed (gm/hr)

$M = O_2$ consumption (liters (S.T.P.)/min)

R.Q. = respiratory quotient (assumed to be 0.84)

t = time (hours)

Skin evaporation only was measured by the analyser, hence, a further correction of weight loss for lung evaporation (E_L) was necessary. Data obtained from the metabolic apparatus made it possible to calculate this value from the equation:

$$E_L = 0.0564\ V\ (VP_E - VP_I)\ t$$

where E_L = lung evaporation in gm/hr.

V = ventilation rate (liters/min)

VP_E = vapor pressure (mm. of Hg.) of expired air (assumed to be saturated at 1°C less than body temperature)

VP_I = vapor pressure (mm. of Hg.) of inspired air

and t = time in hours

The results are shown in table 3. Column 5 gives the weight loss in gm/hr., corrections for lung evaporation and CO_2 excess are listed in column 6 and 7, and the values for skin evaporation in column 8.

5. Derivation of Sensitivity Factors for Individual Experiments

The two values for skin evaporation are compared on a percentile basis in column 10 of table 3. Assuming the one measured by weight loss to be correct, the average recovery using the proposed apparatus was 94% and individual values varied by a maximum of about ± 15% from this average.

TABLE 3

RESULTS OBTAINED ON HUMAN SUBJECTS

1 Subject	2 Ambient Temperature °F	3 Duration of Test Hr.	4* Weight Loss g	5* Rate of Weight Loss g/hr	6 Lung Evap. g/hr	7 CO_2 Excess g/hr	8 E_s from Weight Loss 5 - (6 + 7) g/hr	9** E_s by Integration g/hr	10 Recovery (9/8) %	11 Corr. Factor 20.8 x (8/9) g/hr/μV
A	100.3	7.20	1578	219	6	4	209	188	90	23.0
A	100.3	4.18	948	227	5	4	218	194	89	23.3
A	99.1	7.90	1803	228	4	4	220	201	91	22.8
B	109.8	4.68	1512	323	3	4	316	282	89	23.3
B	109.2	6.68	2082	312	4	5	303	268	88	23.6
B	109.9	7.40	2426	328	3	5	320	262	82	25.3
C	100.6	4.72	977	207	6	3	198	180	91	22.8
C	99.8	7.45	1414	190	5	3	182	170	93	22.3
D	100.4	4.62	1137	246	5	4	237	207	87	23.9
D	99.5	7.12	1610	226	5	5	216	197	91	22.8
D	100.0	8.12	2052	253	6	5	242	235	97	21.4
E	81.3	4.53	193	43	8	4	31	30	97	21.5
E	80.8	6.17	418	68	9	5	54	45	83	25.0
E	81.5	7.15	504	71	10	5	56	54	96	21.6
F	89.6	4.73	529	112	5	3	104	103	99	20.9
F	89.6	7.65	725	95	7	4	84	81	96	21.6
F	89.3	8.80	595	68	5	4	59	57	97	21.4
G	84.2	4.65	253	54	6	4	44	41	93	22.3
G	85.8	6.92	558	81	10	4	67	67	100	20.8
G	84.1	7.88	558	71	8	4	59	52	88	23.6
H	109.3	6.70	2352	351	8	5	338	300	89	23.3
H	109.3	3.18	1098	345	2	4	339	277	82	25.3
I	81.5	5.50	172	31	8	3	20	21	105	19.8
I	84.2	7.50	540	72	7	6	59	54	92	22.6
I	84.0	7.97	302	38	6	3	29	31	107	19.4
J	89.8	6.43	436	68	4	3	61	66	108	19.2
J	90.4	7.87	690	88	4	3	81	75	93	22.3
J	90.2	7.52	507	67	3	4	60	65	108	19.2

* Corrected for water ingested and urine excreted.

** Using average factor, 20.8 g/hr/microvolt deflection.

The constant (20.8 gm. H_2O per hour per microvolt deflection) was then reexamined to determine if consistent errors would be expected on individual runs. This constant was derived from the flow of air through the box and from the average slope of the calibration curves for the analyser.

If the flow, assumed to be constant, were actually higher on certain days, the recovery on these days should have been low. As was stated earlier, only very small variations in the differential head registered by the orifice flowmeter were observed from day to day, and these variations showed no correlation with the per cent recovery.

On the other hand, the average slope of the calibration curves was derived from individual values which showed as wide percentile variations from day to day as did the recoveries in the man runs. It was also shown (table 1) that deviations from a straight line of the points obtained in a single calibration were very small, which indicated that the slope of each curve was constant.

It was believed that the same type of variation in analyser sensitivity was highly probable in the man runs also, and that the recovery for each run reflected a consistent error. Therefore, a different conversion factor was calculated for each test. The corrected factor (column 11 of table 3) was obtained by multiplying the average factor by E_S determined from weight loss (column 8) and dividing by E_S computed by means of the average factor (column 9); this figure was then used for conversion of deflections to evaporative rates, and for calculation of evaporative loss during any portion of the experiment.

III. DISCUSSION

A. The results given in table 3 were obtained by application of the apparatus and method to the measurement of evaporative water loss in a problem of human thermal balance. Normal subjects and subjects with typhoid vaccine induced fever were studied at ambient temperatures ranging from approximately 80° to 110°F. Satisfactory results were obtained during periods of insensible water loss, of profuse and highly variable sweating, and during violent shaking chills. No other method of measurement would have been applicable under all of these conditions.

B. It was possible to measure rapid changes in evaporative rate since a continuous record of this rate was obtained, and not a series of average values for 15 or 20 minute intervals.

C. A portion of a record demonstrating the onset of sweating following a period of insensible loss in a febrile subject is indicated in figure 3B. It is seen that there was a change from a rate of 50 gm/hr. to 280 gm/hr. within a period of only two minutes. Obviously, the measurement of such a change in rate would not have been possible if only average losses for relatively long periods were determined. Figure 3C shows the same type of change; this curve was obtained by redrawing the original record on a time scale reduced to one fourth its normal value, while retaining the normal scale for the deflection. In this way it was possible to indicate a sufficient length of record to demonstrate the difference in types of curves obtained during a period of insensible loss and one of active sweat-

ing. Insensible loss is very stable in rate, but when active sweating starts the rate becomes highly variable.

IV. CONCLUSIONS

A. This apparatus and method described are satisfactory for the measurement of the rate of evaporative water loss from man under a wide variety of experimental conditions.

B. The continuous and almost instantaneous record obtained furnishes more useful information than the average values for relatively long intervals yielded by other methods.

C. The technic should be applicable to problems of thermal balance of clothed and working men, and to the study of the physiological mechanisms which control the rate of water loss from the skin and lungs.

V. RECOMMENDATIONS

It is recommended that this apparatus and method be employed for the measurement of rate of evaporative water loss, particularly in situations where the rate changes rapidly.

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No. 5

AN IMPROVED MOUNTING FOR THERMOCOUPLES FOR THE MEASUREMENT OF THE SURFACE TEMPERATURE OF THE BODY*

by

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from

Medical Department Field Research Laboratory
Fort Knox, Kentucky, 18 March 1947

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*Sub-Project under Studies of Body Reaction and Requirements under Varied Environmental and Climatic Conditions. (M.D.F.R.L.-55). Approved by CG, ASF, 31 May 1946.

No. 5

Project No. 55-2
MEDEA

18 March 1947

ABSTRACT

AN IMPROVED MOUNTING FOR THERMOCOUPLES FOR THE MEASUREMENT OF THE SURFACE TEMPERATURE OF THE BODY

OBJECT

The development of thermocouples to measure accurately the surface temperature of the body.

RESULTS

Thermocouples mounted on copper window screen gave skin temperature readings comparable to those obtained by a radiometer.

CONCLUSIONS

The surface temperature of the body can be measured easily and with accuracy with these thermocouple assemblies.

RECOMMENDATIONS

These thermocouple assemblies are recommended except where the greatest precision is necessary.

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AN IMPROVED MOUNTING FOR THERMOCOUPLES FOR THE MEASUREMENT OF THE SURFACE TEMPERATURE OF THE BODY

I. INTRODUCTION

The intensity of radiation from the skin, measured by a radiometer, provides the best index of the temperature of the outermost surface of the body. The radiometer is an accurate instrument but is technically difficult to employ; it requires daily calibration, the conversion of electrical potentials to temperature is laborious, and an observer or trained subject must hold the instrument in position for each reading. Thermocouples, on the other hand, are technically easy to use, but are often inaccurate for the measurement of surface temperature because of the mountings usually employed. If a naked thermal junction is used, readings are affected by the temperature of the ambient air, and firm contact between the junction and the skin is difficult to maintain. When the thermocouple is protected from the air by a covering, heat loss from the skin is impeded and the readings are too high. The deviation in surface temperature measurements by thermocouple and radiometer is generally 1 degree C. to 3 degrees C. (1).

II. EXPERIMENTAL

A. Apparatus

It proved possible to develop a thermocouple mounting which allowed surface temperature to be determined with much greater accuracy than by those previously employed. This mounting (Figure 1) was made on a 1 x 3 in. rectangle of copper window screen (16 mesh, wire diameter 0.01 in.). Copper-constantan thermocouple leads were used, and kinking was prevented by plastic spaghetti. Double cloth insulation was retained to the point where the wires passed under the screen and single cloth and lacquer insulation were continued up to the junction itself. The insulated portion of the wire was lashed to the screen with thread. The naked leads were twisted together and the junction, one-half inch in length, was soldered to the under side of the screen as indicated. The screen remained quite flexible except for the ends, which were dipped in soft solder to provide firm connections for metal buttons. Adjustable bands of elastic cloth were snapped to these buttons and held the mounting firmly against the skin.

B. Results

Surface temperature measurements using these assemblies were compared with readings obtained by radiometer in four different environments. Thermocouples were fastened to the belly, chest, and thighs of nude subjects and temperatures on adjacent skin areas were determined simultaneously by both methods. The results are shown in Figure 2. The broken lines on each side of the central diagonal show the limits

FIGURE 1

THE THERMOCOUPLE ASSEMBLY

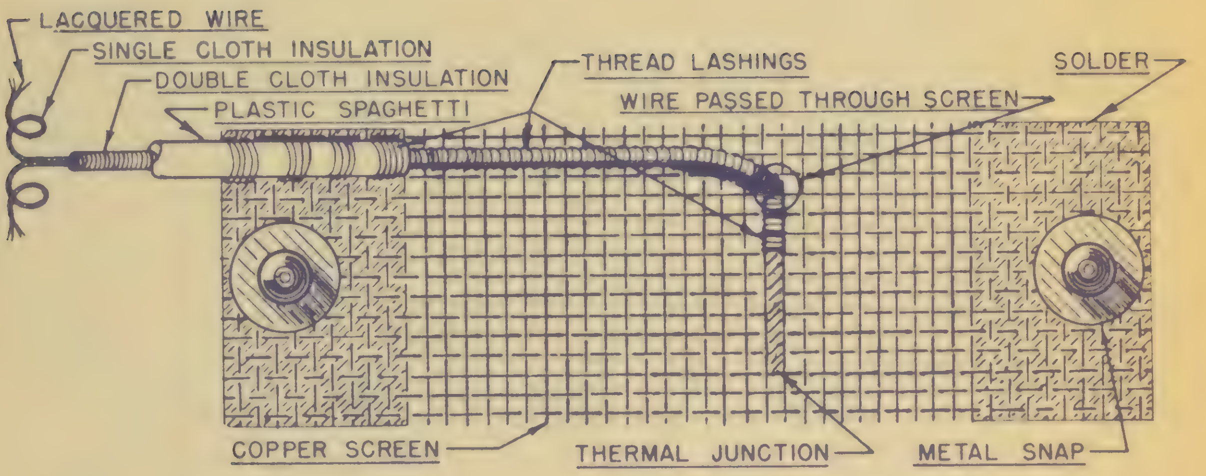
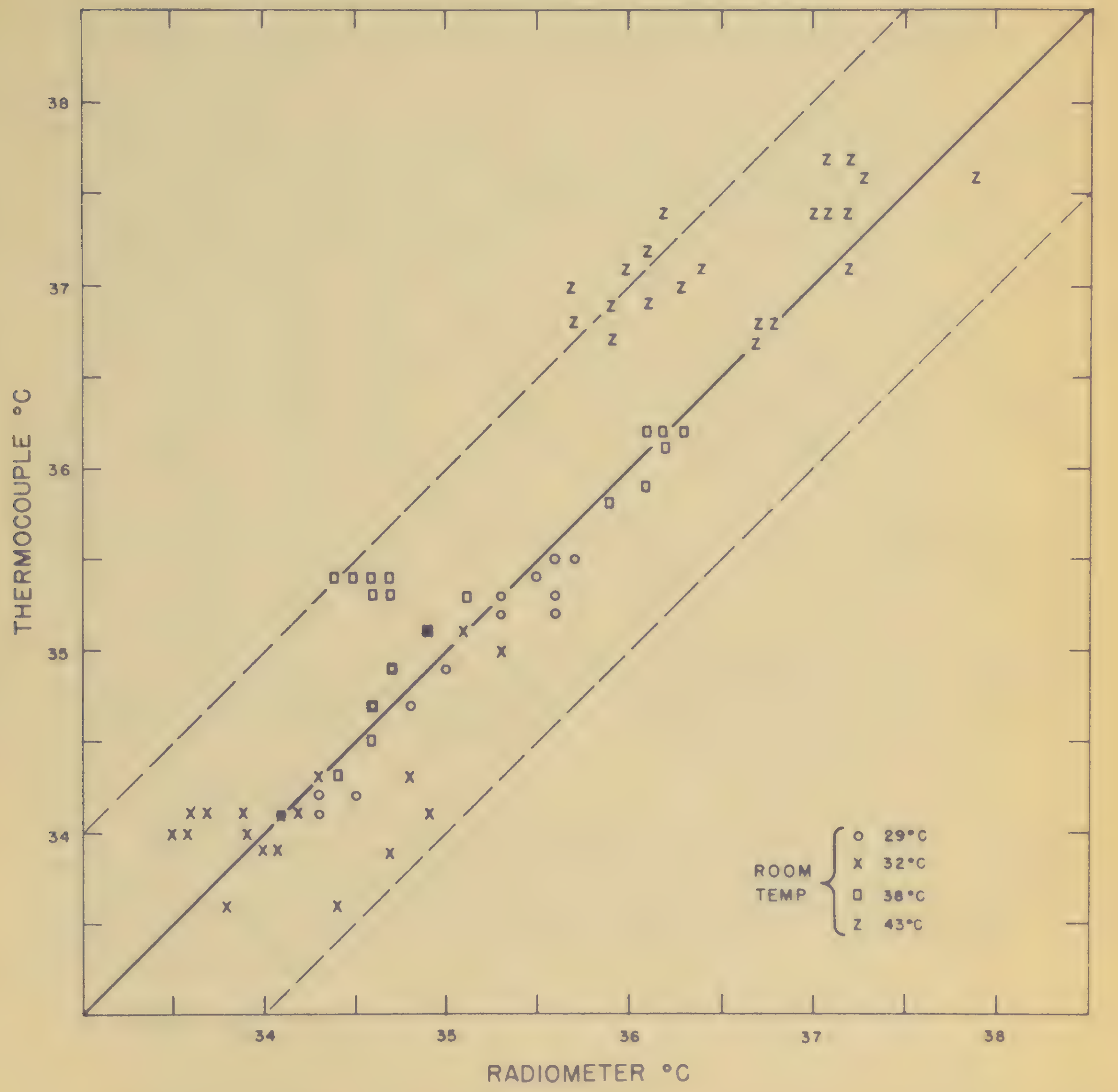


FIGURE 2

COMPARISON OF SIMULTANEOUS THERMOCOUPLE AND RADIOMETER MEASUREMENTS OF SURFACE TEMPERATURES



of variations of ±1 degree C between the readings and enclose 95% of all measurements. Thermocouple and radiometric determinations in each environment were then averaged separately and the values compared (Table 1).

TABLE 1

Comparison of Thermocouple and Radiometer Readings

Room Temp. °C	Number of Values	Avg. Surface Temp. °C		Difference °C
		Thermocouple	Radiometer	
29	16	34.9	35.0	-0.1
32	23	34.2	34.2	0.0
38	24	35.4	35.0	+0.4
43	28	37.1	36.5	+0.6

III. DISCUSSION

It was apparent that the room temperature still had some effect on the thermocouple readings since these were higher than radiometric measurements in hot environments.

IV. CONCLUSIONS

These assemblies proved satisfactory in many studies of long duration. They were easily constructed and quite strong. A large number of mountings could be attached to a subject rapidly and easily, and they always remained firmly in place despite heavy sweating and muscular movement.

V. RECOMMENDATIONS

These thermocouple assemblies are recommended except where the greatest precision is necessary.

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A METHOD OF HUMAN CALORIMETRY*

by

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Medical Department Field Research Laboratory
Fort Knox, Kentucky, 1 April 1947

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*Sub-Project under Studies of Body Reaction and Requirements under Varied Environmental and Climatic Conditions. (M.D.F.R.L.-55). Approved by CG, ASF, 31 May 1946.

Project No. 55-3
MEDEA

1 April 1947

ABSTRACT

A METHOD OF HUMAN CALORIMETRY

OBJECT

To develop an improved method of human calorimetry.

RESULTS

The subject was observed in a small chamber. An air conditioning unit supplied a constant flow of air through this chamber at closely controlled temperatures and humidities. Air movement within the chamber was regulated by a fan.

Evaporation was determined by use of an infra-red gas analyzer (12). Metabolic heat production was calculated from the rate of oxygen consumption, measured continuously by a closed circuit apparatus. Radiative transfer was calculated from the average wall and skin temperatures which were measured by specially designed thermocouple assemblies - (13). The change in heat content for the entire experiment was determined from changes in the rectal and mean skin temperatures. This value was substituted in the thermal equation, $C = \Delta H/t - (M + E + R)$, to obtain an average rate of convection. This rate of convection was partitioned over short intervals according to the difference between air and mean skin temperatures. The short interval values of convection were then substituted in the thermal equation to give short interval values for ΔH.

CONCLUSIONS

The particular advantages of this method are:

1. Each component of the thermal balance can be determined either continuously or at short intervals.

2. Rapidly changing and high rates of evaporation and metabolism can be determined without difficulty.

3. The method can be applied to a wide variety of experimental conditions.

RECOMMENDATIONS

It is recommended that this method, or portions thereof, be considered by agencies planning to undertake problems of human calorimetry.

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A METHOD OF HUMAN CALORIMETRY

I. INTRODUCTION

A. Previous Methods

The two best known methods of human calorimetry are respiration calorimetry (1,2,3) and partitional calorimetry (4,5). The former is the more accurate, but the latter can be applied to a much wider variety of experimental conditions (6,7,8,9,10,11). In both methods evaporation and metabolism are determined at relatively long intervals, making it impossible to measure rapid changes in thermal balance.

B. Method to be Described

The method to be described minimizes these difficulties by use of a new apparatus for the continuous measurement of evaporation (12), new thermocouple assemblies for the measurement of skin temperatures (13), a simple experimental chamber, a modified closed circuit metabolic apparatus, and a modified method of calculation of results.

II. EXPERIMENTAL

A. Apparatus and Methods

1. Experimental Chamber

a. Description

The experimental chamber (Fig. 1) consisted of a heavy wooden frame, 8 x 3 x 3 feet, supporting double walls of thin plastic sheeting. The subject lay inside on a waterproofed netting, and was observed through the transparent walls of the chamber door. He breathed into a mouthpiece connected to rubber tubes, and these passed through the walls to a metabolic apparatus outside. Leads from a potentiometer entered the chamber and terminated in multiple contact plugs for the attachment of thermocouple assemblies.

A constant flow of air was maintained through the chamber, and an even distribution of the stream was ensured by a thick baffle of hair felt just beyond the air inlet.

The experimental chamber was placed in a large, air-conditioned room.

b. Control of Environment

The temperature and humidity of the entering air were closely regulated by a Carrier air conditioner. This unit delivered about 60 cubic feet a minute and, since the volume of the chamber was only 70 cubic feet, the replacement of air was rapid. A fan at the foot of the chamber, when operating at low speed, merely mixed the air at the outlet; conditions inside were those of a well ventilated but not windy room. Greater wind movement could be obtained at higher fan speeds.

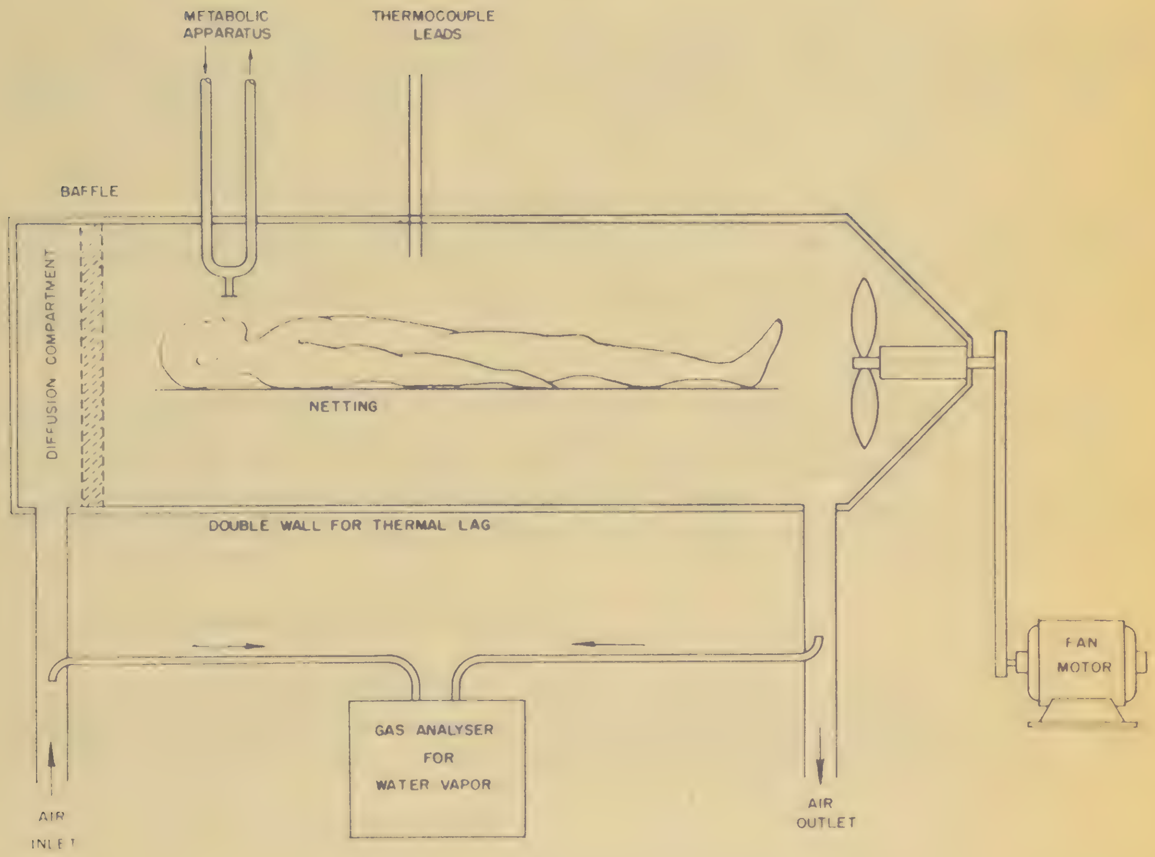

FIG. I. EXPERIMENTAL CHAMBER

The room and chamber were conditioned to approximately the same temperature, and the thermal lagging of the chamber made the internal environment independent of small fluctuations in external temperature. The internal environment was not always uniform, however, because air currents of varying temperature and vapor pressure were produced by convection and evaporation from the subject's body.

2. Determination of Evaporation

Evaporation was determined continuously and nearly instantaneously by means of an infra-red gas analyzer (12) described elsewhere.

3. Determination of Metabolism

Metabolic heat production was measured by an apparatus (Fig. 2) which recorded oxygen consumption, respiratory pattern, and pulmonary ventilation. This apparatus differed in several respects from those previously described (14,15,16).

Air leaving the spirometer was saturated at the prevailing spirometer temperature when this was below 90°F.; at higher temperatures, saturation was incomplete but the air was unpleasant to breathe. A water-jacketed heat exchanger was used for cooling and the cooled air was always saturated.

A kymograph with smoked paper was used for all recordings. A clock marked a time scale in minutes and the respiratory pattern was traced directly by the movement of the spirometer counterbalance. Pulmonary ventilation was recorded in units of 170 liters by an electrically wired ventilometer (17), and the replacement of oxygen in units of 3 liters by the wet test meter.

4. Measurement of Temperatures

Copper-constantan thermal junctions, calibrated against a radiometer (18,19,20), were used for all temperature measurements. Voltage readings were taken with a Leeds and Northrup type K potentiometer.

a. Air Temperature

Air temperature was measured at 4 positions inside the chamber, and at the inlet and outlet. Random fluctuations, due to thermal currents produced by the subject, occurred at all points except the inlet and it was not possible, therefore, to develop a satisfactory weighting formula for the average air temperature. The best index of this average was the temperature of the inlet air, and this was used for the calculation of convection.

b. Wall Temperature

The temperatures of the inside surfaces of the chamber were measured at 4 points by thermocouples fastened firmly to the long walls above and below the subject, and by thermocouples in the air near the

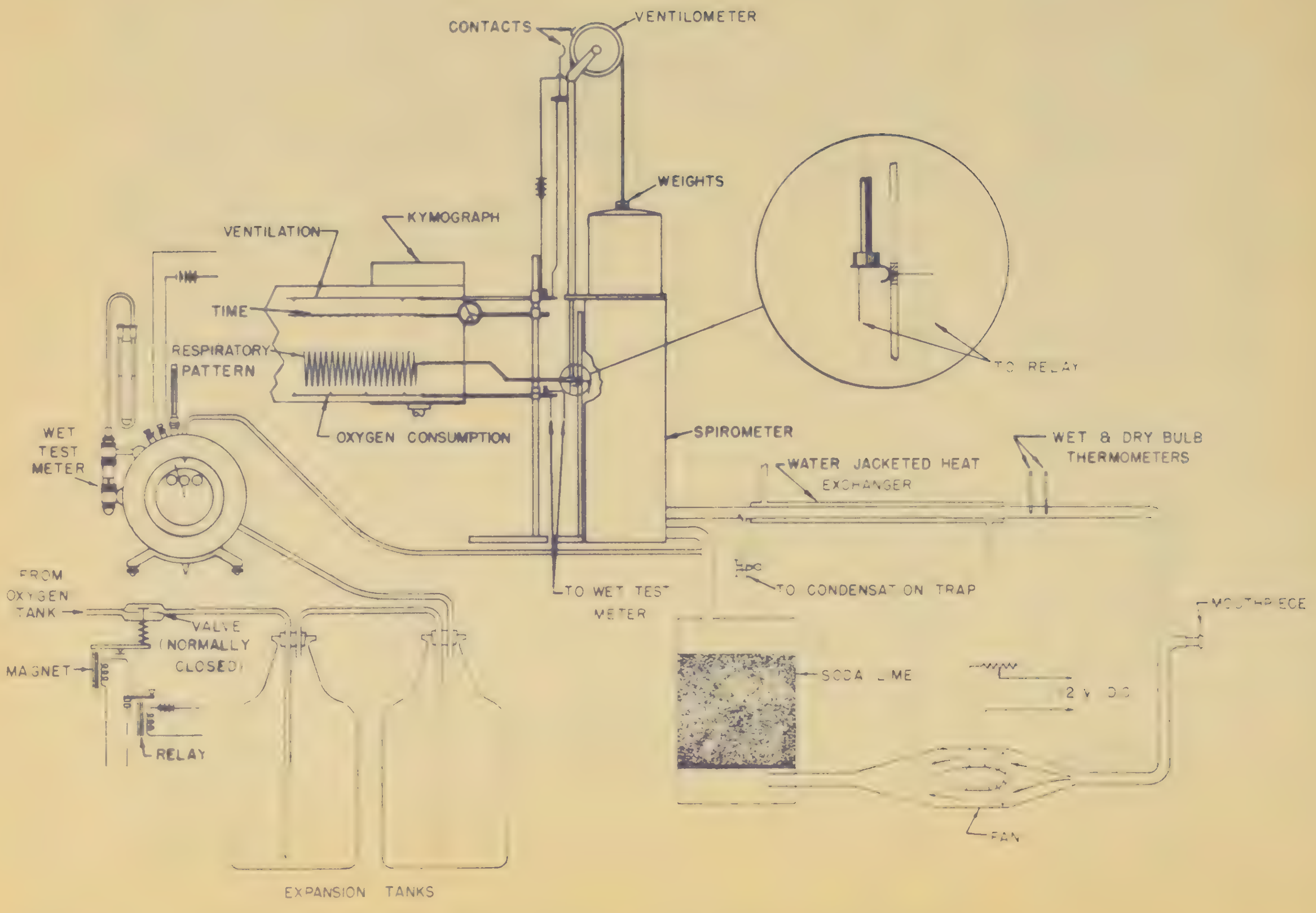

FIG. 2. APPARATUS FOR MEASURING OXYGEN CONSUMPTION

end walls. The measurements agreed satisfactorily with simultaneous readings by a radiometer. The average surface temperature was obtained from a formula in which the long walls were weighted 4 times as heavily as the small end walls.

c. Skin Temperature

New thermocouple assemblies (13) developed during this study were used to measure the surface temperature of the skin. The readings were found to be accurate when checked by a radiometer. Ten assemblies were used and the reading of each was weighted according to the area of skin represented by its position on the body (21). The weighted values (Table 1) were added to give the mean skin temperature.

TABLE 1

POSITION AND WEIGHTING FACTORS FOR SKIN THERMOCOUPLES

POSITION	WEIGHTING FACTOR
Chest	0.08
Back	0.08
Belly	0.09
Right Thigh	0.12
Left Thigh	0.13
Forearm	0.14
Calf	0.15
Dorsum of Hand	0.06
Dorsum of Foot	0.05
Forehead	0.10
Number of Couples: 10	Total 1.0

d. Rectal Temperature

Rectal temperature was measured by an inlying thermocouple, mounted inside a thin-walled silver capsule, 1 cm. in diameter and 4 cm. in length.* Four thermal junctions, wired in parallel, were cemented around the inside wall of the capsule near the distal end. This assembly gave accurate readings and had a very short response time. It was inserted at least 7 cm. (22).

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* We are grateful to Dr. S. M. Horvath and Mr. D. Little for the design and construction of this mounting.

B. Procedure

About 45 minutes were required to stabilize the temperatures and humidities of the environments inside and outside the chamber. During this time the thermocouples were attached to the subject's skin. At the start of the experiment proper, the subject was weighed, entered the chamber, and began breathing into the metabolic apparatus.

Significant readings could not be obtained for 5 to 10 minutes because of the time necessary for clearance of room air from the chamber and for stabilization of the altered inside environment. Evaporation was measured continuously; metabolism was recorded by units of 3 liters of oxygen; and a complete series of rectal, skin, wall, and air temperatures was taken at 15 minute intervals.

Water was supplied at body temperature through a rubber tube lead-into the box and, when urination was necessary, the box was opened and the experiment interrupted for a few minutes. The quantity and temperature of fluids ingested or excreted were measured.

At the end of the experiment, the subject was weighed immediately.

For the conduct of an experiment three operators were desirable. One of these recorded all temperatures and regulated the environmental conditions; the second operated the equipment for measuring evaporation; and the third observed the subject and controlled the metabolic apparatus.

C. Calculation of Thermal Balance

1. General

An imbalance between the rates of gain and loss of heat by the body produces a change in body heat content, the magnitude of which depends on the degree of imbalance and the time for which it persists. This relationship can be stated in the form of the equation:

$$\Delta H = (M + C + R + E)\, t,$$

where ΔH = change in heat content of the body (Cal)
M = metabolism (Cal/hr)
C = convection (Cal/hr)
R = radiation (Cal/hr)
E = evaporation (Cal/hr)
t = time (hr)

When heat flows into the body through any channel the rate is considered positive, and when heat flows out of the body it is considered negative.

Two other factors in rates of heat transfer could be added to this equation: (1) conduction; (2) ingestion or excretion of matter. These were negligible in this method.

The principles by which the individual components of the equation were calculated have been reported from the Russell Sage Institute (21,23,24), the Pierce Laboratory (5,7,25,26,27,28) and elsewhere (9,10,11).

2. Primary Calculations

a. Metabolism (M)

Metabolic heat production was calculated from the rate of oxygen consumption, recorded by units of 3 liters of moist gas, using an arbitrary R.Q. value of 0.84 (29).

b. Evaporation (E)

Evaporation from the lungs was calculated from the vapor pressure difference between inspired and expired air and ventilation rate; evaporation from the skin was determined from the difference in water vapor concentration at the chamber inlet and outlet and the flow of air through the chamber (13).

c. Changes in Heat Content (Δ H)

The change in body heat content for the entire experiment was calculated from the change in average body temperature, which was computed from the changes in rectal (deep tissue) and mean skin (peripheral tissue) temperatures. The formula used was developed by Burton (30) and modified by Hardy and DuBois (31). The change in rectal temperature was weighted 4 times as heavily as the change in mean skin temperature.

The change in average body temperature, multiplied by the mass and specific heat of the body, gave the change in heat content. The specific heat was considered to be 0.83 (30) and the mass was the average of the initial and final balance weights.

d. Radiation (R)

Radiation was calculated by the principles outlined by Hardy and DuBois (21). The details of the calculations are contained in an earlier report from this laboratory (9). The radiation profile of the nude subject in the supine position was taken as 0.8 of his total surface area.

e. Pulmonary Convection

Pulmonary convection was calculated from the temperature difference between inspired and expired air, ventilation rate, and the specific heat of air (approximately 0.0003 Cal/liter). This value was so small that it could be neglected generally, otherwise it was added to the value for skin convection.

3. Secondary Calculations

a. Convection (C)

Average convection for the entire experiment was computed by substituting the results of the primary calculations in the thermal equation and solving for C:

$$C = \frac{(\Delta H}{t} - (M + R + E)$$

The value of ΔH was subject to error because the changes in rectal and mean skin temperatures were imperfect indices of the change in average body temperature. When _t_ was large, the expression $\frac{\Delta H}{t}$ became small, and the intrinsic error in ΔH had a negligible effect on the value of C. This was not the case, however, when _t_ was small, and it was necessary to adopt another method of computing C for short intervals.

This calculation was based on the principle that the rate of convective heat exchange was proportional to the square root of the wind velocity and the difference between the air and mean skin temperatures (10,26). Since wind velocity was constant, convection was a function of the temperature gradient only. Average convection calculated from the thermal equation, was divided by the average gradient for the whole experiment, and a coefficient was obtained expressing the rate of heat transfer in Cal/hr/°C. Convection over a short period was then computed by multiplying this coefficient by the temperature difference for the interval.

b. Change in Heat Content (ΔH)

H for short intervals was then obtained by substituting the short-term value of convection in the thermal equation.

4. Practical Considerations

About 4 man-hours were required for the analysis of 1 hour of data collection.

D. Application

The method was used in 27 experiments in which the thermal balance, of reclining normal or febrile subjects, was determined in studies lasting 6 to 8 hours. Test environments ranged in temperature from 27° to 43°C. with a vapor pressure of about 7 mm. Hg and a wind movement of 15 feet per minute. The results of these experiments will be reported separately (32). Pilot experiments were conducted on clothed and working men.

III. DISCUSSION

The reliability of the method rested fundamentally on the primary determination of M,R,E and ΔH. Only a small error was introduced into the calculation of metabolic heat production by failure to determine an R.Q. value.

The reliability of the method for measuring evaporation has been discussed previously (12).

An error was incurred in the primary short-term calculation of ΔH. These values lagged behind those yielded by secondary calculation during

times of large and rapid change. The primary short-term calculations were obviously incorrect since these values, substituted in the thermal equation, yielded highly inconsistent and sometimes absurd results for convection. Hence, the primary calculation of Δ H was applied only to long periods of time in which rapid changes in temperature had no effect.

Several errors present in the measurement of radiation were due chiefly to imperfect temperature measurements and failure to account for changes in the radiation profile.

The accuracy with which average convection could be determined depended on the long-term measurements of the primary factors. The least reliable of these was radiation and, in the final evaluation of the method, the partition of C and R was the least satisfactory procedure. Analysis of all runs suggested that an overall error of 10-15 per cent might occur but this was not generally a serious drawback, since C and R were parallel functions. In partitioning convection over short intervals, another error was superposed due to the fact that the effective wind velocity was altered when the pattern of muscular activity was changed.

The short-term calculation of Δ H also reflected the errors due to changes in effective wind velocity, but it was not affected by errors in the basic partition of C and R, since it was calculated from the sum of these components.

IV. CONCLUSIONS

The particular advantages of this method are:

A. Each component of the thermal balance can be determined either continuously or at short intervals.

B. Rapidly changing and high rates of evaporation and metabolism can be determined without difficulty.

C. The method can be applied to a wide variety of experimental conditions.

V. RECOMMENDATIONS

It is recommended that this method, or portions thereof, be considered by agencies planning to undertake problems of human calorimetry.

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no. 7

THERMAL REGULATION DURING EARLY ACCLIMATIZATION TO WORK IN A HOT DRY ENVIRONMENT*

by

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*Sub-project under High Temperatures, Study of Physiological Effects of. (M.D.F.R.L. 2-17-1). Approved September 1942.

no. 7

Project No. 2-17-1
MEDEA

30 June 1947

ABSTRACT

THERMAL REGULATION DURING EARLY ACCLIMATIZATION TO WORK IN A HOT DRY ENVIRONMENT

OBJECT

To determine the changes in thermal regulation of early acclimatization to a hot, dry environment.

RESULTS AND CONCLUSIONS

Calorimetric measurements and clinical observations during early acclimatization were made on three men working at a metabolic rate of 180 Cals/m^2/hr in a very hot, dry environment.

On beginning work in these surroundings, heat was gained at a high rate by metabolism, convection and radiation. Deep and peripheral tissue temperatures rose rapidly. The climb in skin temperature reduced the environmental stress, since it diminished the thermal gradient for convection and radiation. At the same time, however, the internal gradient for the outflow of heat from the deep tissues was narrowed and the deep temperature rose excessively despite a greatly elevated peripheral blood flow. The heavy load on the circulation probably accounted for many of the symptoms of the unacclimatized state.

The principal thermal adjustment of acclimatization was the development of a higher rate of sweat secretion. The added cooling by evaporation lowered the skin temperature and improved the internal thermal gradient. Heat outflow from the deep tissues was increased and a reduction in peripheral flow was possible. Signs of circulatory stress diminished greatly. The heat content of the body after acclimatization remained high, but the heat was absorbed in the peripheral tissues and the critical deep tissue temperature was maintained at a nearly normal value.

RECOMMENDATIONS

None.

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THERMAL REGULATION DURING EARLY ACCLIMATIZATION TO WORK IN A HOT DRY ENVIRONMENT

I. INTRODUCTION

A. Acclimatization

When man works for the first time in a very hot environment his body temperature rises to an abnormally high level. This is associated with psychomotor, gastro-intestinal, and circulatory disturbances which often prevent effective work and may lead to heat exhaustion. On repeating the work in the same hot environment on successive days, he becomes acclimatized (1,2,3,4,5); that is, he develops protective mechanisms which allow him to control his temperature at a level compatible with satisfactory physiological function, and to work nearly as easily in the heat as in the cool.

B. Rectal and Skin Temperature during Work

The experiments of Nielsen (6) demonstrate that if work is carried out at a constant metabolic rate, the rectal temperature during a period of 40-50 minutes rises to a plateau value, the height of which is proportional to the metabolic rate and independent of the environmental conditions unless these are extreme. It appears, therefore, that the elevated rectal temperature of work is under physiological control and is not the result of inability to dissipate the increased metabolic heat because, if this were the case, the temperature would be lower in cool environments where heat loss can be accomplished much more easily. Nielsen noted that this control cannot be maintained in very hot environments and abnormally high temperatures are reached. The skin temperature, on the other hand, is always influenced by the thermal nature of the surroundings and is normally higher in hot environments (6,7).

C. Heat Content and Thermal Flows

Changes in the rectal temperature can be used as rough indices of changes in the average temperature of the deep tissues of the body (8), and variations in the mean skin temperature indicate in similar fashion the variations in temperature or heat content of the peripheral tissues. Burton and Hardy and DuBois (8,9) have developed empirical formulas in which measurements of the rectal and mean skin temperatures are combined to indicate the change in the average temperature or heat content of the body as a whole. A change in heat content can also be determined by the method of partitional calorimetry, developed by Winslow, Herrington, and Gagge (10,11). The rates of production and transfer of heat from man to his environment are measured separately in each channel of flow, and are added algebraically to give the net rate of gain or loss of heat by the body. When the net rate is multiplied by time the change in heat content is obtained:

$$\Delta H_{body} = (\text{net rate})(\text{time}) = M + E + C + R\ (\text{time})$$

where
M = the rate of metabolic heat production
E = the rate of evaporative heat loss
C = the rate of heat transfer by convection to the surrounding air
R = the rate of heat exchange with the environment by radiation

By combining these calorimetric procedures it is possible to obtain a rough measure of thermal flow from the deep tissues to the surface by direct tissue conduction and by transport in the blood stream (12). From the last, the volume of the "peripheral" blood flow can be estimated.

These relationships were investigated in men working in the heat to determine if possible the mechanisms preventing the excessive rise in body temperature as acclimatization developed.

II. EXPERIMENTAL

A. Apparatus and Methods

1. General Design of the Experiment

The temperatures and thermal flows of 3 subjects were determined during 1 hour of work on 10 successive days in the heat, a period long enough for the early changes of acclimatization to occur (2,4). The test hour of work was divided into five 12 minute intervals in each of which measurements were made.

2. The Environment

A hot, dry (desert) type of environment was chosen for study in which the air and radiation temperatures of the walls were 120° F., the wet bulb temperature 80° F., and the wind velocity 450 feet per minute. These conditions imposed a large convective and radiative heat load on the subject, and the evaporation of sweat was rapid.

3. Subjects and Schedules

The physical characteristics of the soldiers who served as subjects appear in Table 1. These men were brought into good physical condition by long daily marches during a preliminary period of 23 days. In the last 9 days of this time they practiced treadmill walking and other phases of the routine followed subsequently in the heat. During the final 5 days, measurements were made under the same conditions of work as in the heat, but in a cool, windy environment with air and radiant temperatures of 78°F. and a wet bulb temperature of 60°F.

TABLE 1

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject	Age yrs.	Height cms.	Weight Kg.	S. A. M^2
A	18	178	68.5	1.87
B	20	171	61.9	1.73
C	25	179	72.9	1.91
Average	21	176	67.8	1.84

On each of the 10 "hot days" which followed, the men were exposed to high environmental temperatures for a total of 7 hours. Measurements were always made in the first, or test hour, and the men then rested until the last 2 hours when they again worked at a metabolic rate of approximately 180 Cals/m^2/hr. When not in the test environment, the subjects lived in a laboratory room conditioned to 78°F.

Further control data were collected in the original cool environment in the 2 days which followed the period of heat exposure.

All determinations were made with the subject in the nude except for shoes and socks.

Base line measurements of skin temperature, rectal temperature, and pulse rate were made in a cool, still air environment of 78°F. just before the start of every test hour.

4. The Test Hour

Calorimetric determinations were made in a wind tunnel placed in the center of a laboratory room. The floor of the tunnel consisted of a treadmill on which the subject walked, facing the air stream, at 2.5 miles per hour up a 2.5% grade. In each test hour, there were five 10 minute periods of marching separated by 2 minute intervals in which the man stepped off the mill and seated himself on a balance in a wind shielded booth. The wind velocity and the temperatures of the air, tunnel walls, and skin were measured during each marching period. The metabolic rate was measured throughout the 1st, 2nd, and 5th periods. The weight and rectal temperature were determined in each 2 minute interval in the booth.

The pulse rate was counted during each working period, and blood pressure measurements on a tilt table were made at the finish of the hour. Water at body temperature and salted to 0.1% was drunk during each interval in the weighing booth in an amount approximately equal to the quantity lost by sweating.

5. Methods of Measurement

a. Environment

Dry and wet bulb temperatures of the air were measured by mercury thermometers in motor driven psychrometers. Air movement was determined by a hot wire anemometer and an Alnor velometer. The radiant temperature was obtained by averaging the readings of a radiometer pointed at the 6 presenting wall surfaces.

b. Body Temperature

Rectal temperature was measured by clinical rectal thermometers. The temperature of the skin was determined radiometrically at 6 points and each reading was weighted according to the area of skin represented (Hardy and DuBois 13,14,15) and summed to give the mean skin temperature (Table 2).

TABLE 2

WEIGHTING FACTORS FOR THE DETERMINATION OF THE MEAN SKIN TEMPERATURE

Area	Cheek	Forearm	Palm	Thigh	Back	Chest	Total
Weighting %	14	11	5	32	17	18	100

c. Oxygen Consumption

Expired air was collected in a Tissot gasometer and duplicate samples were analyzed for CO_2 and O_2.

d. Weight Change

A beam balance sensitive to 4 g. was used.

e. Pulse Rate

This was determined by palpation.

B. Calculations

1. Calculation of the changes in body heat content

a. The change in heat heat content of the body was calculated from the specific heat and the changes in the rectal and mean skin temperatures (8,9).

$$\Delta H_{total} \text{ in Cals.} = (0.67\ \Delta T_r{}^{\circ}C. + 0.33\ \Delta T_s{}^{\circ}C.)(\text{Wt. in Kg.})(0.83)$$

b. This was roughly partitioned into changes in the heat content of the deep and peripheral tissues:

$$\Delta H_{deep} \text{ in Cals.} = (0.67\ \Delta T_r)(\text{Wt. in Kg.})\ (0.83)$$

$$\Delta H_{peripheral} \text{ in Cals.} = (0.33\ \Delta T_s)\ (\text{Wt. in Kg.})\ (0.83)$$

2. Calculation of Heat Flow

a. Metabolism (M) was calculated from the oxygen consumption using the caloric equivalent of oxygen at the measured R.Q., and correcting for external work.

b. Evaporation (E) was calculated from the water loss by the skin and lungs in a given time, and the latent heat of vaporization of water (0.576 Cal/g). Water loss was measured by weight change, corrected for water ingestion and the excess of CO_2 excreted over O_2 consumed:

$$E \text{ in Cals/hr} = \frac{(0.576\ \text{Cals/g})(\text{Wt.}_{\text{corr.}})}{(t \text{ in hr.})}$$

c. Convection and radiation were calculated as the sum of both factors, ($C + R$):

Because wind velocity in this experiment was constant, convection varied only with the difference between the air and mean skin temperature:

$$C = K_c(T_a - T_s)$$

The radiating surface area and emissivities of the man and his surroundings were assumed to be constant, therefore radiation varied only with the difference between the 4th powers of the absolute values of wall and mean skin temperature (14):

$$R = K_r \left(T_w^4 - T_s^4\right)$$

When the 1st power difference was substituted for the 4th power difference in this last relationship only a small error was introduced, since measurements were confined to a narrow range of temperatures. As air and wall temperatures were always the same, C and R were considered functions of the same temperature difference.

Convection and radiation were first calculated for all experimental periods in which there was no change in rectal and skin temperatures. Under these circumstances, there was no change in heat content, and the algebraic sum of all heat flows equalled zero:

$$M + E + C + R = 0$$

This equation could be solved for $C + R$, since M and E had been already determined. A large number of coefficients for $C + R$ transfer per degree of temperature difference between the air and skin was then calculated:

$$K_{C + R} \text{ in Cals/hr/}^{\circ}\text{C} = \frac{C + R \text{ in Cals/hr}}{T_a - T_s}$$

The average of these values was 18 Cals/hr/°C.

Using this coefficient, $C + R$ was then calculated for all periods according to the difference between the air and mean skin temperature, regardless of any change in heat content:

$$C + R \text{ in Cals/hr} = (18)(T_a - T_s)$$

d. In certain cases $C + R$ was partitioned roughly by making an independent calculation of R, using the method described by Hardy and DuBois (14).

e. The thermal flows were summed and the overall, or net rate of gain or loss of heat to the body was determined. Heat gains were considered positive and heat losses negative. The net rate was multiplied by the time and a second value for the change in body heat content was obtained:

$$\Delta H \text{ in Cals/hr} = (M + E + C + R)\ (t)$$

3. Calculation of the "peripheral" blood flow

Peripheral blood flow was calculated by the method of Hardy and Soderstrom (12), using the equation:

$$P\,F = \frac{\dfrac{M - \Delta H}{t}}{T_r - T_s} - K_{cd}$$

where P F = "peripheral" blood flow in liters/m^2/hr (equivalent to Cals/m^2/hr/°C)

and K_{cd} = conductivity of peripheral tissue in Cals/m^2/hr/°C

4. General

All calculations were made for each subject individually but, as the trend of results was similar for all men after corrections for differences in surface area, the results were combined into average values.

C. Results

1. Clinical Observations

During the 10 days in the hot environment, the characteristic sequence of reactions of early acclimatization appeared in all 3 subjects (1,2,3,4,5). On the 1st day the men completed the test hour with great difficulty, and all complained of great fatigue, dizziness, and a sense of oppressive heat. There was marked flushing of the face, the gait became unsteady, and 2 of the men developed orthostatic hypotension with syncope shortly after stopping work. On the 2nd day, these symptoms and signs were less marked and by the 4th and 5th days had nearly disappeared. On the 10th day the men worked easily, and there was nothing in their appearance to suggest any strain not incurred by the same work in the cool.

The pulse rate climbed progressively on the 1st day to reach an average value at the end of the hour of 160 beats per minute (Fig.1, top panel). In the ensuing 4 days, the rate dropped markedly, showing a definite tendency to reach plateau values. On the 10th day, the pulse rate rose only to 125, but this was 15 beats per minute higher than the rate in the cool, and evidenced that some additional stress on the circulatory system still remained.

2. Rectal and Mean Skin Temperatures

The rectal temperature in the cool environment rose rapidly at first but levelled off in the last periods of each hour of work (Fig. 1, 2nd panel). The final temperatures reached were nearly the same from day to day and established roughly the normal plateau value of deep temperature of 37.8°C. for the grade of work being carried out.

The rectal temperature on the 1st day in the heat, on the other hand, rose rapidly and continuously to 39°C. (102.2°F.), exceeding the normal value by 1.2°C., and it probably would have climbed higher had the work

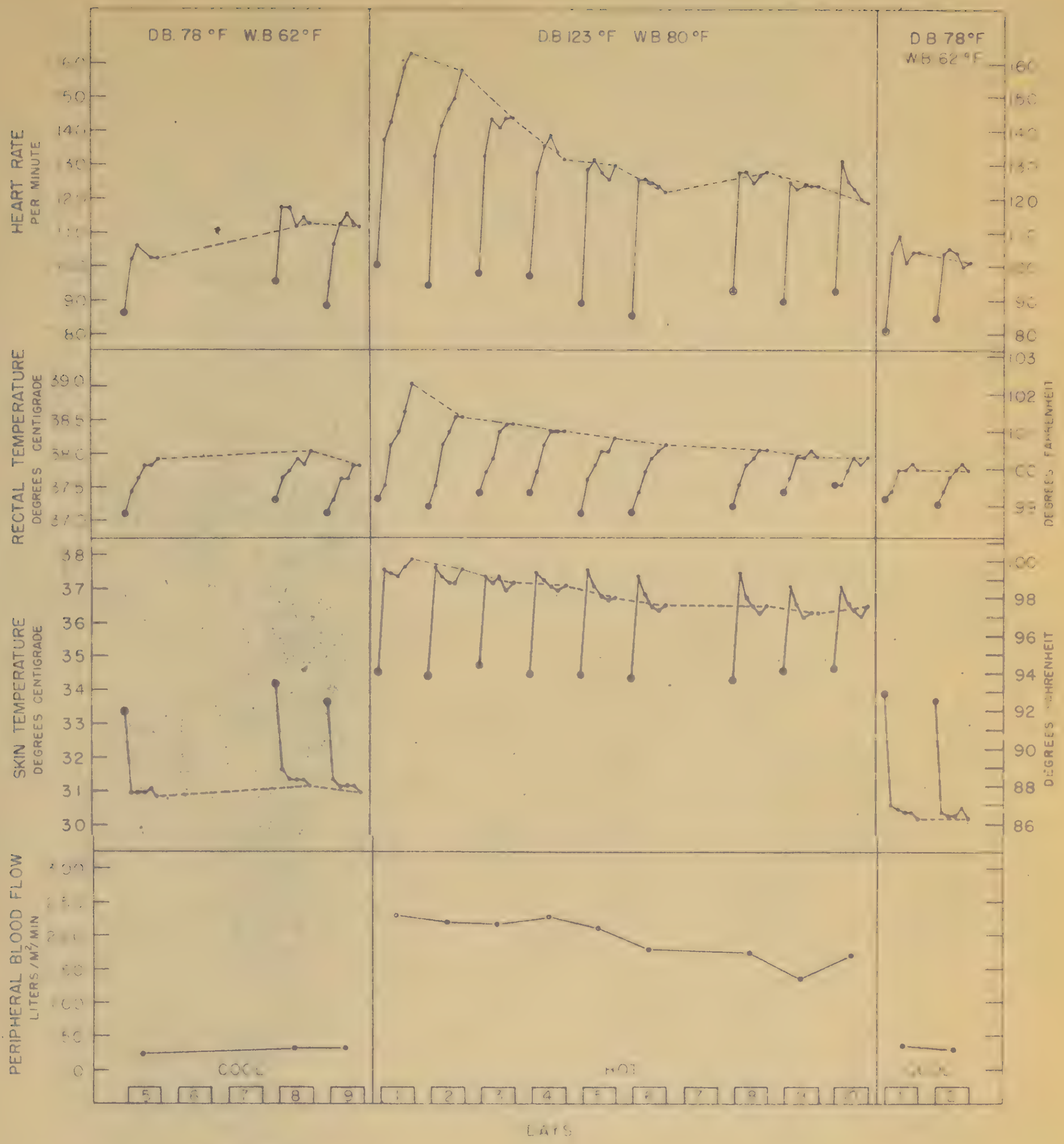

Fig. 1. The Heart Rate, Rectal and Mean Skin Temperature and Peripheral Blood Flow during Work in the Cool and during Acclimatization to the Same Work in Severe Heat.

In the upper three panels the solid lines connect the base line determinations taken at rest in a cool environment (large points) with the five readings (small points) taken in the course of the test hour on each day. The broken lines connect the final readings from day to day. In the 4th panel, the values are averages for the entire hour.

periods been extended. On the 2nd day, this rise was considerably less and became progressively lower on each of the following days, until, on the 10th day, the final reading obtained was 38°C. (100.4°F.). This was only 0.2°C. above the average value established in the cool. In the last days in the hot environment, a tendency for the temperature to level off at a plateau value was quite distinct and the readings on the 9th and 10th days were very nearly the same, suggesting that any further fall in temperature would be slight. It was clear, therefore, that as acclimatization progressed the excessive rise in deep temperature had been largely prevented and, after 10 days in the heat, thermal regulation had improved sufficiently to control this temperature to near normal levels.

The skin temperature in the cool environment fell sharply below the base line readings as the subject began work in the wind tunnel (Fig. 1, 3rd panel). After the initial drop, the values remained fairly stable in the remainder of each test hour at an average figure for all cool days of 30.5°C. This was roughly 7°C. below the average deep temperature, and established a large gradient for the outflow of heat from the deep tissues to the surface of the body.

The mean skin temperature in the first few minutes of work on the 1st day in the heat rose precipitously above the base line level to the very high value of 37.5°C. (99.5°F.), and subsequently in the course of the hour it climbed slightly higher (Fig. 1, 3rd panel). In the following days, the initial spike remained high but by the 3rd day, a definite tendency appeared for the temperature to fall thereafter, and this fall was pronounced by the 10th day. The overall drop in the final skin temperature during the 10 days was slightly greater than the parallel fall in final rectal temperature (broken lines) and thus improved the internal thermal gradient for heat flow to the skin. In the 1st hour in the heat, for example, the average difference between deep and skin temperature was only 0.8°C., a difference so small that heat did not move in sufficient quantity to the surface of the body, and the deep temperature rose excessively. By the last day, this gradient was 1.3°C., still a very small value, but nevertheless a significant increase.

3. Peripheral Blood Flow

The peripheral blood flow (Fig. 1, bottom panel) was very nearly the same in all cool days. On the 1st hot day, a sevenfold increase to a very high value occurred. The flow diminished markedly as acclimatization progressed, but remained far above the level in the cool.

4. Changes in Heat Content

In the cool environment there was an average loss in body heat content of 22 Cals/m^2. This was due to a large drop in the peripheral temperature which outweighed the rise in deep temperature. In all days in the heat, on the other hand, there was a big gain in heat content since both the rectal and skin temperatures rose above the base line readings. On the 1st day this was 71 Cals/m^2 but, in the following days, the gain became progressively smaller until by the 10th day it was only 35 Cals/m^2, an amount still 57 Cals/m^2 above the final values reached in the cool.

When the changes in heat content for the hot and cool days were partitioned between the deep and peripheral tissues an interesting relationship appeared. Deep heat content in the cool environment rose on the average 10 Cals/m^2. In the hot environment on the 1st day the deep heat content rose 35 Cals/m^2, but by the 10th day it rose only 12 Cals/m^2 or 2 Cals/m^2 above the level in the cool. The total difference of 57 Cals/m^2 between the final total heat content in the heat and in the cool was almost entirely (97%) explained by a change in heat content of the peripheral tissues only.

These changes in temperature, blood flow, and heat content, which had been accompanied by parallel and marked improvement in clinical symptoms and signs, were due to physiological adjustments which accelerated the rates of heat transfer from the man to his environment.

5. Thermal Balance

The rates of gain and loss of heat in the cool and hot environments have been charted day by day in Figure 2A. In the cool, metabolism was the only channel of heat gain; evaporation, radiation and convection were routes of heat loss. The net thermal flow, or algebraic summation of all rates, can be visualized by the difference in the height of the columns of each pair. In the cool days, generally, the rate of loss exceeded by a small margin the rate of heat gain, leading to a slight fall in heat content.

The effect of the hot environment was striking. Here, heat was gained by metabolism at a rate nearly the same as in the cool and, in addition, by convection and radiation which had now become very large channels of thermal inflow. The only remaining means for cooling was evaporation and although this rate increased thirteenfold, it was not sufficient to balance the rate of gain; there remained, therefore, a large net flow into the body leading to the excessive rises in body heat content in the first days of exposure.

The changes in thermal flows during the hot days are shown more clearly in Figure 2B. The rate of heat gain by metabolism (1st panel) diminished uniformly but the overall fall was slight (8 Cals/m^2/hr). It was not clear from these data whether this change was a part of the acclimatizing process, as was maintained in studies by Robinson *et al.* (2), or a training effect due to practice in treadmill walking. On the other hand the rate of heat gain by convection and radiation increased (2nd panel). The total rise of 19 Cals/m^2 was explained by the fall in skin temperature previously noted. While this change widened and improved the internal thermal gradient for the outflow of heat from the deep tissues, at the same time it widened the thermal gradient between the body surface and the environment. Since convection and radiation were functions of the skin to environmental temperature difference, the flow of heat into the body by these channels was increased. The net effect of alterations in metabolism, convection and radiation led to an overall rise in the rate of heat gain to the body of 11 Cals/m^2/hr.

The rate of body cooling, however, rose to a greater extent. The total gain in evaporation was 40 Cals/m^2/hr, (3rd panel), with the most rapid changes taking place in the first 4 days, the period of time that was apparently of the most importance in the acclimatizing process. The in-

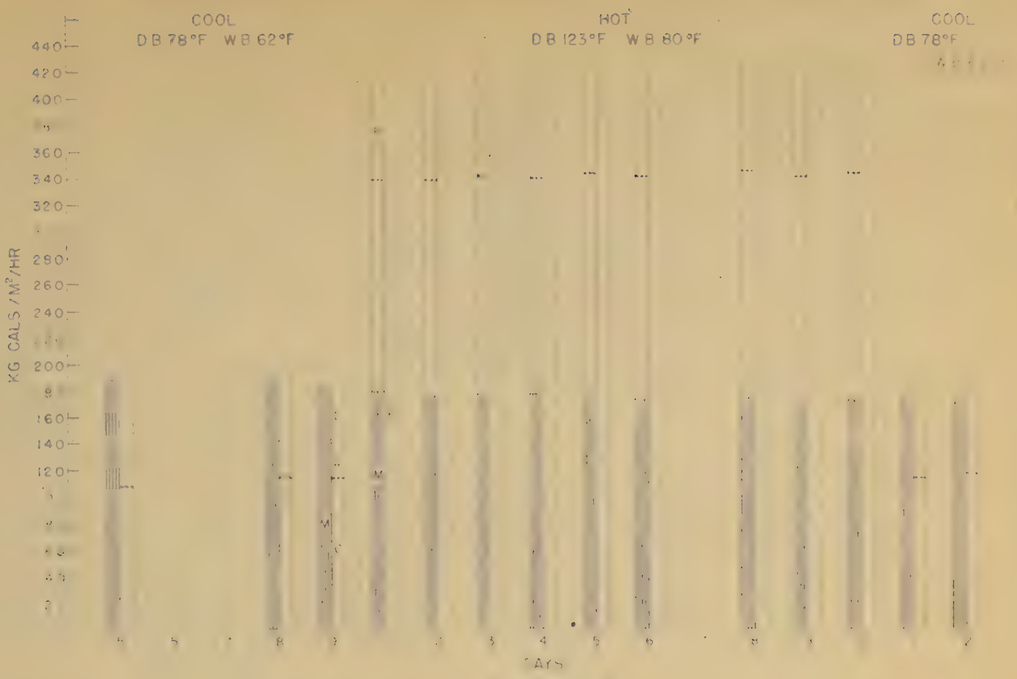

FIG. 2 A

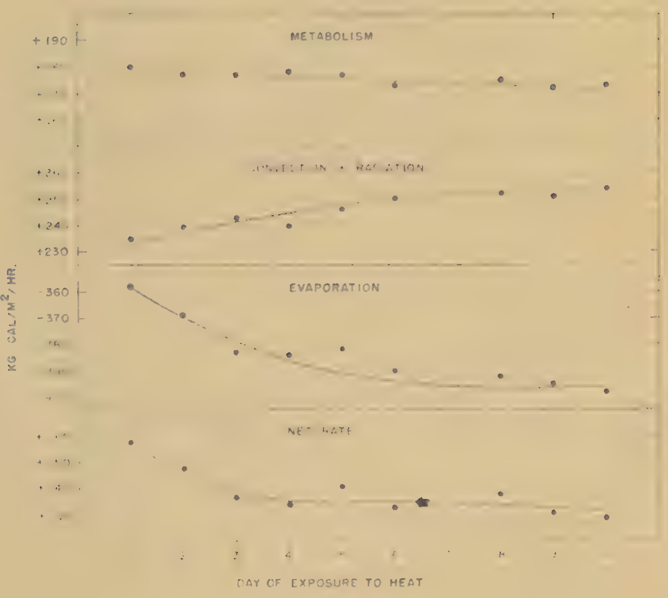

FIG. 2B

Fig. 2A. Thermal Flows during Work in the Cool and Hot Environments.

The left column of each pair show the channels and magnitude of thermal inflows to the body, and the right column the thermal outflows. Key: M - Metabolism; C - Convection; R - Radiation; E - Evaporation

Fig. 2B. The Changes in Thermal Flows during Acclimatization.

creased cooling could only be explained by a higher rate of sweat secretion.

The sum of all changes in heat flows was a considerable decrease in the net rate of heat gain to the body (bottom panel). Thus the lowered temperatures and heat content observed during the progress of acclimatization could be explained.

It could be demonstrated that thermal balance was restored by determination of the rates of heat exchange by periods within each test hour. In Figure 3, these rates are plotted for the hour of work on the 1st day (solid line), and the 10th day (broken line) for 12 minute intervals. Metabolism was constant on the 1st day but fell slightly on the 10th day (1st panel). Convection plus radiation, on the other hand, rose to an appreciably higher rate on the 10th day (2nd panel). The greatest difference occurred in evaporation (3rd panel). Values on both days were similar in the first 12 minute interval, but, in the 2nd period on the 10th day, evaporation rose and remained a larger value during the rest of the hour. These changes resulted in the net flows of heat shown in the bottom panel. It can be seen on the 1st day, that the initial high rate of gain was considerably reduced between 12 and 24 minutes, but the lowest value reached at any time was 27 Cals/m^2/hr; in other words, heat flowed into the body throughout the hour, and body temperature and heat content were always rising. The situation was quite different on the 10th day. Heat flowed into the body at a high rate in the first 12 minutes, but thereafter the rate fell for practical purposes to zero. Thus, thermal imbalance existed only in the first part of the hour, and it was in this time interval that the major rises in rectal and skin temperature occurred. In the remainder of the hour the men were in thermal equilibrium: the rates of inflow and outflow were approximately equal, and heat content and body temperatures were stabilized.

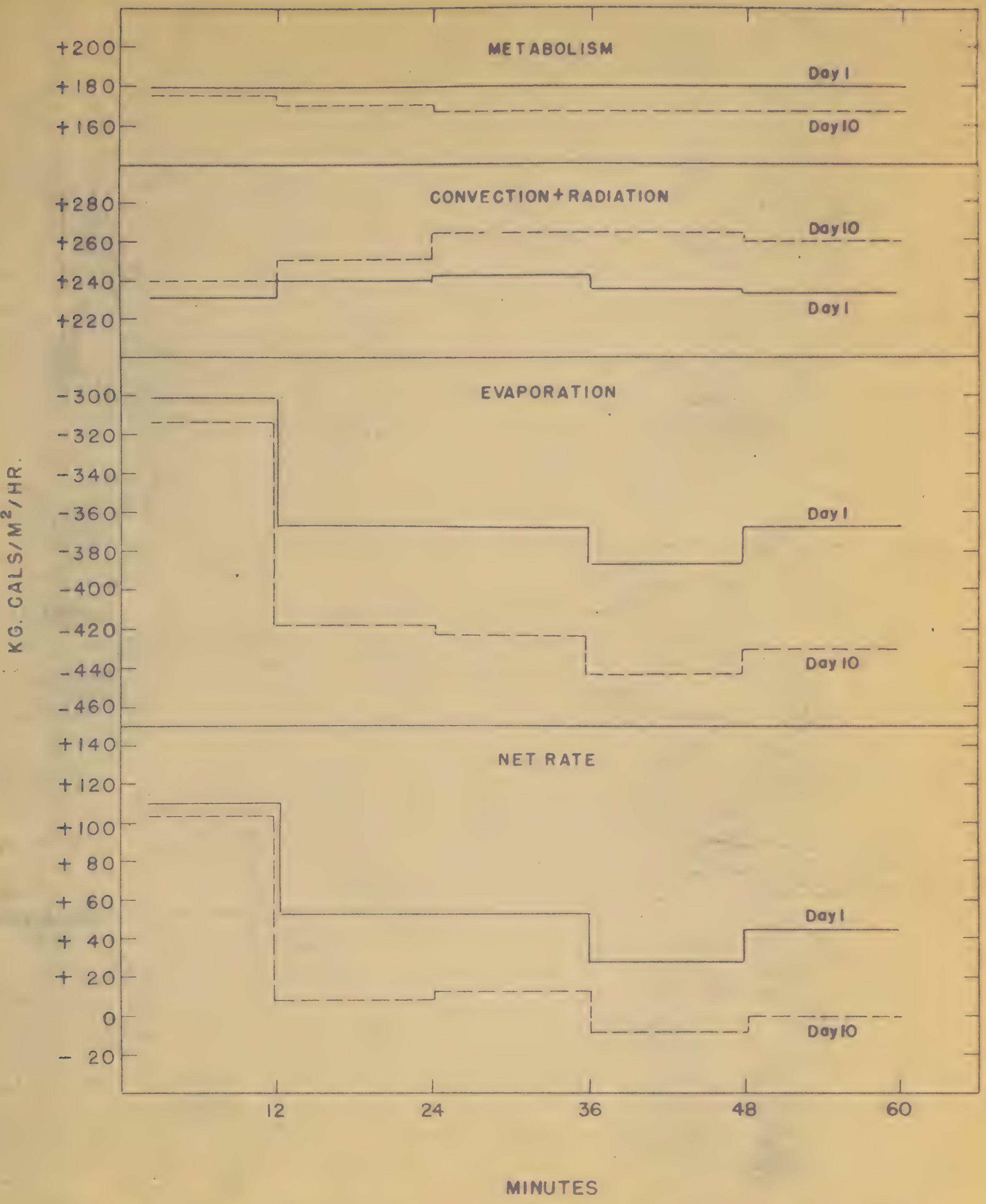

Fig. 3. The Restoration of Thermal Balance during Acclimatization.

The rates of gain and loss of heat to the body are shown by 12 minute intervals during the test hour on the 1st and 10th day of work in the heat.

III. DISCUSSION

The temperature of the deep tissues, or some part of these tissues, is apparently critical to normal physiological function; otherwise, it would be difficult to explain the observations of Nielsen (6) and the evidence of this study that the rectal temperature is regulated to the same value in men working at a given rate in widely different types of environment. When the environment is so hot that physiological controls are inadequate to maintain this temperature, severe clinical symptoms and signs are manifested, as noted in the first test days of this study.

The principal thermal adaptation of acclimatization was the ability to secrete sweat at a more rapid rate. The total increase in evaporation by the 10th day was 40 Cals/m^2. The net cooling effect was less, however, since the skin temperature was lowered and heat gain by C + R was greater by 19 Cals/m^2. The lower skin temperature permitted a greater outflow of heat from the deep tissues, and the net cooling advantage of 21 Cals/m^2 was adequate to ensure a nearly normal deep temperature. The heat content of the acclimatized man was still 57 Cals/m^2 higher than when working in the cool, but only 3% of this was in the deep tissues and 97% was in the peripheral tissues, the absolute temperature of which is not apparently critical to normal physiological function.

The ability of the peripheral tissues to take up large quantities of heat without leading to significant changes in the deep temperature is an important mechanism in thermal regulation. First, it permits the body to endure large imbalances in the rates of gain and loss of heat over considerable periods of time, and obviates the necessity for precise adjustments in the control of thermal flows. Rapid fluctuations in environmental and working conditions can be encountered without immediate changes in peripheral blood flow, sweating, or heat production. Second, the absorption of heat causes the temperature of the skin to approach the environmental temperature and diminishes heat exchange by convection and radiation. The skin temperature in the heat, for example, rose 3°C. above the base line value reducing the heat load on the man through C + R by 54 Cals/m^2/hr.

Different levels of peripheral temperature in relationship to the deep temperature are possible because of changes in the peripheral blood flow. Thus, on the 10th day, when the peripheral temperature was high and the internal gradient small, a sufficient outflow of heat to the surface occurred because of the large peripheral flow. A sufficient rise in flow to compensate for narrowing of the gradient can occur within certain limits only. In the unacclimatized state, the gradient was too small and, despite a very high flow, the normal deep temperature was exceeded.

The requirement for a greatly elevated peripheral flow combined with the demand for blood to the active muscles placed a heavy load on the circulation. This seems the most probable explanation for the severe symptoms of circulatory insufficiency on first exposure to the heat.

IV. CONCLUSIONS

On beginning work in the test environment, heat was gained at a high rate by metabolism, convection and radiation. Deep and peripheral tissue temperatures rose rapidly. The climb in skin temperature reduced the environmental stress, since it diminished the thermal gradient for convection and radiation. At the same time, however, the internal gradient for the outflow of heat from the deep tissues was narrowed and the deep temperature rose excessively despite a greatly elevated peripheral blood flow. The heavy load on the circulation probably accounted for many of the symptoms of the unacclimatized state.

The principal thermal adjustment of acclimatization was the development of a higher rate of sweat secretion. The added cooling by evaporation lowered the skin temperature and improved the internal thermal gradient. Heat outflow from the deep tissues was increased and a reduction in peripheral flow was possible. Signs of circulatory stress diminished greatly. The heat content of the body after acclimatization remained high, but the heat was absorbed in the peripheral tissues and the critical deep tissue temperature was maintained at a nearly normal value.

V. RECOMMENDATIONS

None.

VI. BIBLIOGRAPHY

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No. 8

PRELIMINARY OBSERVATIONS ON PHYSIOLOGICAL, NUTRITIONAL, AND PSYCHOLOGICAL PROBLEMS IN EXTREME COLD. FORT CHURCHILL, CANADA (WINTER, 1946-1947).

By

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From

Medical Department Field Research Laboratory
Fort Knox, Kentucky

3 July 1947

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RESTRICTED

No. 8

TABLE OF CONTENTS

RESTRICTED

Section I

INTRODUCTION

A. Test Group, Test Situation and Program

On 17 November 1946 the Arctic Test Branch of the Engineer Board, Fort Belvoir, Virginia arrived at Fort Churchill, Manitoba, Canada for six months testing of various types of engineering equipment. The unit consisted of 4 officers, 80 enlisted men, and 30 civilian specialists. All officers and civilians, and about half of the enlisted personnel volunteered for the assignment. The test program, carried on jointly with the Canadian Army, consisted of the following projects: (1) bridging and boats; (2) camouflage; (3) demolition; (4) engine generator and flood lighting; (5) fire fighting; (6) infra-red testing; (7) motor vehicle servicing; (8) processing and packing methods; (9) road and airfield construction; (10) snow removal equipment; (11) water supply.

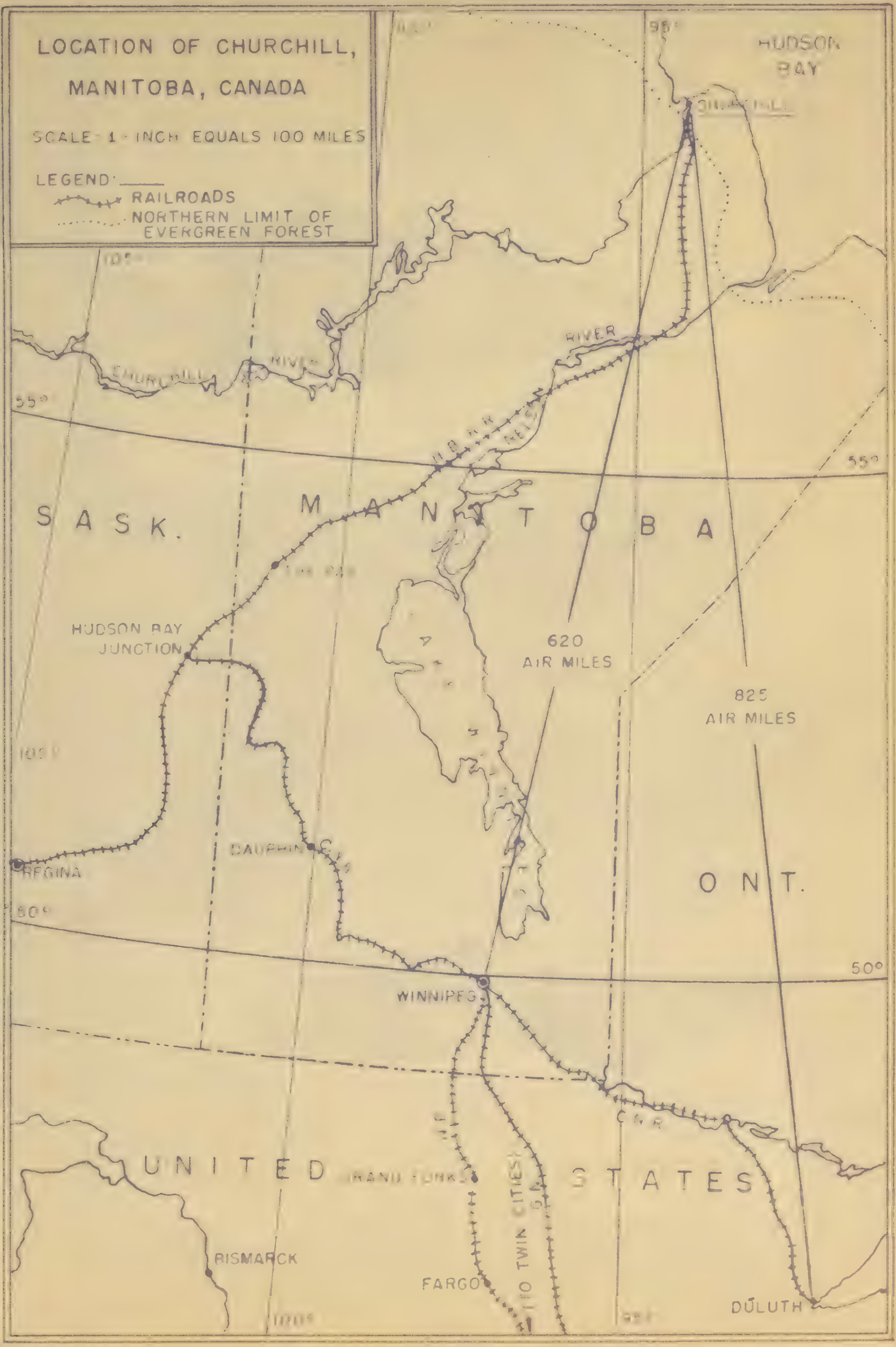
All personnel lived in wooden barracks heated by oil-burning stoves, and were fed in a regular Canadian Army mess. Clothing and equipment were standard U. S. Army arctic issue. All 80 U. S. Army enlisted men were available as test subjects.

A medical unit, consisting of one officer and two enlisted men, was attached to the Arctic Test Branch. The duties of this unit were: (1) to provide medical care for all United States personnel on duty at Churchill; (2) to act as observer and consultant on medical and physiological problems associated with testing of engineer equipment; (3) to carry out a program of physiological observations in the field; (4) to make general observations of problems and field expedients in the Arctic. For medical care Fort Churchill Military Hospital was available and quite adequate. A building of 1200 square feet floor space was converted into a field research laboratory.

B. Characteristics of Churchill and Vicinity

Churchill lies about half way up the west coast of Hudson Bay about longitude 94, latitude 59—approximately 500 miles south of the Arctic Circle. It is at the mouth of the Churchill River and is the terminus of the Hudson Bay Railroad (see map). The population of Churchill, consisting of whites, Indians, and Eskimos, is small and nomadic in nature. Last available figures give a population of 500 in 1941. The inhabitants are chiefly trappers, fur traders, or employees of the railroad or Harbor Board.

Fort Churchill is located four miles south of the town of Churchill on bluffs overlooking Hudson Bay. The camp, consisting of about sixty semi-permanent wooden frame buildings, was erected in 1943 by the U. S. Army Air Forces as headquarters and main airport for the Crystal Route to Europe. It was used for Lend-Lease transport to Britain and planned



LOCATION OF CHURCHILL, MANITOBA, CANADA

SCALE 1 INCH EQUALS 100 MILES

LEGEND

MEDICAL FIELD RESEARCH LABORATORY
FORT CHURCHILL, CANADA

FORT CHURCHILL MILITARY HOSPITAL

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as a center for air evacuation of casualties. As a result, the two main establishments are the airport (two 6500-foot concrete runways, control tower, weather and radio station, and hangar) and a standard 200-bed general hospital building (now used as officers' quarters, administrative offices, and base hospital).

The area around Churchill is flat and is not wooded, except for very small stunted trees (chiefly white spruce) about 6 to 8 feet high scattered sparsely over the country. To the south lies the sub-arctic forest and to the north the barren wastelands of the true Arctic. There are many small lakes and streams. The lakes can be used for small aircraft on floats in the summer and on skis in the winter. Dog teams are used for transportation in winter and tractor trains have been employed successfully for some 20 years. The foreshore of the Hudson Bay is clay containing many boulders and with a gradual slope out to sea. There is about a 14-foot tide which uncovers approximately 500 to 1,000 yards of beach at low tide. In places the shore is sandy but these places are few. Between July and October coastal navigation is by small boat. There is very little regular navigation in the bay. The Hudson's Bay Company runs a supply boat two or three times per year, and there are some small boats belonging to trappers or traders. In winter the bay is frozen over. The sea-ice close to the shore is very rough due to movement of the ice caused by the tide and wind.

Around Churchill itself and at some places up the west coast of Hudson Bay there are low rocky outcrops but the average terrain is flat muskeg (tundra). This is frozen in the winter to a depth of more than 200 feet and even in the summer it only thaws to a depth of 18-36 inches. It can be walked on with rubber boots. Around Churchill itself good gravel is available in large quantities, and is used extensively for roads, streets, and building purposes.

Section II

WEATHER DATA

Weather data and forecasts are provided daily by a modern, completely equipped, and fully staffed Canadian Government meteorological station at Fort Churchill Airport. Mimeographed sheets are distributed each day giving the following information at six hour intervals: (1) temperature; (2) wind direction and velocity; (3) wind chill; (4) visibility; (5) relative humidity; (6) precipitation; (7) barometric pressure readings. In addition daily reports of the following are given: (1) maximum temperature; (2) minimum temperature; (3) total precipitation; (4) time of sunrise and sunset; (5) weather forecast. These weather reports are the source of the data presented in Tables 1 and 2.

At Churchill the maximum temperatures vary from 22°F. in February to 87°F. in July and the minimum temperatures vary from -57°F. in January to 30°F. in August. The average wind velocity is 15-20 mph from the north or northwest, but blizzards up to 50 mph are quite common. These high winds and low temperatures serve to give Churchill one of the most severe "wind chill factors" in any inhabited area.

"Wind chill" or dry-shade atmospheric cooling as defined by Dr. Paul A. Siple, is a measure of the quantity of heat which the atmosphere is capable of absorbing from one square meter exposed surface within one hour. It is expressed in kilogram calories per square meter per hour per degree C. (0.369 BTU per square foot per hour per degree F.) The original formula, as developed by Paul A. Siple, Ph.D. and Charles F. Passel of the United States Antarctic Service, was derived from a large number of experiments based upon the carefully measured freezing time of a cylinder of water exposed in open atmospheric conditions which varied widely in temperature and wind velocity. Wind chill is of great physiological significance in that "it expresses the rate at which the body of a naked human being would lose heat if placed out of doors under given conditions, and indicates the potential cooling value of the atmosphere as a stress on the human body" (1).

The average monthly precipitation at Churchill varies from 0.3 inch in January to 2.9 inches in July. The snow varies but does not average more than two or three feet in depth although, due to frequent high winds, deep drifts are likely to occur. The average relative humidity during the winter varies from 90% to 95%. In spite of the high relative humidity the moisture content of the air is extremely small.

Tables 1 and 2 are summaries of weather data at Fort Churchill from November 1946 to March 1947. Table 3 shows the average winter weather conditions at Churchill for the ten year period, 1936-1945. The data in Table 3 were obtained from the Controller, Meteorological Service of Canada, D.O.I., 315 Lewis Street, Toronto 5, Ontario, Canada.

It may be pointed out that Churchill offers three weather conditions for cold experimentation: (1) extreme cold (-20°F. to -50°F.); (2) severe wind chill (average wind velocity of 15-20 mph but 40-57 mph frequent);

(3) Blowing snow (visibility at times is less than 10 feet).

A weather classification based on temperature and wind chill was compiled in 1943 by the Climatology Unit of the Research and Development Branch of the Office of the Quartermaster General, as follows:

I. Cold -
  1. Temperature: 14°F. (-10°C.) to 32°F. (0°C.)
  2. Wind Chill Factor: Under 1100 kg.cal./sq.m./hr.

II. Very Cold -
  1. Temperature: -4°F. (-20°C.) to 14°F. (-10°C.)
  2. Wind Chill Factor: 1100-1400 kg.cal./sq.m./hr.

III. Extreme Cold -
  1. Temperature: -40°F. (-40°C.) to -4°F. (-20°C.)
  2. Wind Chill Factor: 1400-1800 kg.cal./sq.m./hr.

IV. Ultra Cold -
  1. Temperature: Under -40°F. (-40°C.)
  2. Wind Chill Factor: Over 1800 kg.cal./sq.m./hr.

Thus, on the basis of temperature alone Churchill weather during January and February is classified as extreme cold, but on addition of the factor of wind chill its classification becomes that of ultra cold. Winter weather conditions at Churchill are truly arctic, but the relatively warm months of July and August place it in the general classification of sub-arctic weather. The Arctic Region is defined as "any area of the Northern Hemisphere having an average temperature of below 10°C. (50°F.) for the warmest month and an average temperature of below 0°C. (32°F.) for the coldest month" (2). Thus, many areas of the Arctic Region have much warmer winters than those found at Churchill.

References:

1. Climatic Research Unit, O.Q.M.G. Table of Wind Chill Values. (War Department, 1943).

2. War Department TM1-240. Arctic Manual. (17 January 1944).

TABLE 1

SUMMARY OF WEATHER DATA

FORT CHURCHILL, CANADA

(WINTER, 1946-1947)

	NOV. 1946	DEC. 1946	JAN. 1947	FEB. 1947	MAR. 1947
MEAN TEMPERATURE[1]	+ 4.1	- 7.2	- 17.1	- 14.0	+ 0.7
MAXIMUM TEMPERATURE[1]	+ 31.6	+ 27.6	+ 6.7	+ 18.0	+ 24.0
MEAN MAX. TEMPERATURE[1]	+ 9.8	- 0.4	- 106	- 8.7	+ 7.9
MINIMUM TEMPERATURE[1]	- 24.0	- 33.7	- 38.8	- 35.8	- 23.0
MEAN MIN. TEMPERATURE[1]	- 1.7	- 14.1	- 23.6	- 19.3	- 6.5
MEAN RELATIVE HUMIDITY	92 %	94 %	90 %	92 %	95 %
MEAN MAX. WIND VELOCITY[2]	22	20	20	19	18
MEAN MAX. WIND CHILL[3]	1610	1670	1899	1785	1578
TOTAL PRECIPITATION[4]	0.54	1.49	0.44	0.56	0.59

1 - ALL TEMPERATURES ARE IN DEGREES FAHRENHEIT.

2 - WIND VELOCITY VALUES ARE MILES PER HOUR.

3 - WIND CHILL VALUES ARE KILOGRAM CALORIES PER SQUARE METER PER HOUR.

4 - PRECIPITATION IS SNOW EXPRESSED IN INCHES OF WATER EQUIVALENT.

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TABLE 2

DISTRIBUTION OF DAYS IN WEATHER RANGES.

	NOV. 1946	DEC. 1946	JAN. 1947	FEB. 1947	MAR. 1947	TOTAL
MINIMUM TEMPERATURE (°F.) —						
ABOVE 0	13	2	0	3	9	27
0 TO - 9	5	9	2	3	7	26
-10 TO -19	8	10	7	7	10	42
-20 TO -29	4	7	12	10	5	38
-30 AND BELOW	0	3	10	5	0	18
MAXIMUM WIND VELOCITY[1] —						
0 TO 9	1	1	0	1	6	9
10 TO 19	9	15	16	13	11	64
20 TO 29	14	10	14	14	11	63
30 AND ABOVE	6	5	1	0	3	15
MAXIMUM WIND CHILL[2] —						
BELOW 1400	13	3	0	3	10	29
1400 TO 1600	1	9	3	2	5	20
1600 TO 1800	9	8	7	9	12	45
1800 TO 2000	6	5	12	11	4	38
2000 TO 2200	1	5	7	3	0	16
ABOVE 2200	0	1	2	0	0	3

1 — WIND VELOCITY VALUES ARE MILES PER HOUR.

2 — WIND CHILL VALUES ARE KILOGRAM CALORIES PER SQUARE METER PER HOUR.

TABLE 3

AVERAGE WINTER WEATHER CONDITIONS AT CHURCHILL, CANADA

(FOR TEN YEAR PERIOD, 1936-1946)

	NOV	DEC.	JAN.	FEB.	MAR
MEAN TEMPERATURE	+ 6 °F	- 11 °F	- 19 °F	- 17 °F	- 6 °F
MEAN WIND VELOCITY[1]	17	15	15	15	14
MEAN WIND CHILL[2]	1440	1680	1820	1765	1585
TOTAL PRECIPITATION[3]	1.03"	0.66"	0.48"	0.61"	0.87"

1- WIND VELOCITY VALUES ARE MILES PER HOUR

2- WIND CHILL VALUES ARE KILOGRAM CALORIES PER SQUARE METER PER HOUR

3- PRECIPITATION IS SNOW EXPRESSED IN WATER EQUIVALENT.

Section III

OBSERVATIONS ON CLOTHING

A. Introduction

Eighty U. S. Army enlisted men were stationed at Fort Churchill, Canada from November 1946 to April 1947 for the purpose of testing the effect of extreme cold upon the performance of engineering equipment. Each EM was issued arctic clothing and equipment specified by Army Table of Equipment 21, as follows:

Bag, sleeping, Arctic	1	Parka, field, pile	1
Boots, Blucher, high top	1 pr	Parka, wet weather	1
Boots, mukluk	2 pr	Shirt, flannel, OD	2
Cap, field, pile, OD.	1	Shoes, Arctic, felt	1 pr
Drawers, long, wool	1 pr	Shoepacs, M1944	1 pr
Gloves, shell, leather	1 pr	Socks, wool, cushion sole	5 pr
Gloves, insert, wool	2 pr	Socks, wool, ski	4 pr
Goggles, ski-mountain	1	Socks, felt	2 pr
Jacket, field, M1943	1	Sweater, high neck, OD	1
Jacket, field, pile	1	Trousers, field, wool, OD	2 pr
Mittens, Arctic	1 pr	Trousers, field, cotton, OD	2 pr
Muffler, wool, OD	1	Trousers, wet weather	1 pr
Overcoat, parka type	1	Undershirt, wool	3

(Nomenclature used is that specified in W.D. TM10-275)

Observations were made concerning the adequacy of the above clothing both as to (1) warmth and protection against cold, and (2) suitability for the particular tasks performed. This study was carried out by means of (1) questionnaires answered by the test subjects, and (2) observation of personnel at work under arctic field conditions.

In cooperation with Canadian Army observers a comparison was made of the relative merits of Canadian and American types of clothing and equipment. Also available was the opportunity to observe the testing of several new types of cold weather clothing by Dr. A. H. Woodcock of Canadian Research and Development.

B. Procedures, Results, and Discussion

1. Tabulation and Analysis of Clothing Questionnaires

In December 1946 and in February 1947 all U. S. Army enlisted personnel at Fort Churchill filled out questionnaires giving the following information: (1) Type of work performed; (2) Hours of outside exposure daily; (3) Adequacy of clothing for subject's particular work (yes or no); (4) Three best features of clothing issued; (5) Three worst features of clothing issued. The answers to these two sets of questionnaires have been tabulated, analyzed, and correlated with field observations.

The eighty test subjects are arbitrarily divided into three groups: Group I of 26 subjects with outside exposure range of 0-2 hours daily; Group II of 27 subjects with outside exposure range of 3-5 hours daily; Group III of 27 subjects with outside exposure range of 6-8 hours daily. Table 4 shows the adequacy of clothing in relation to weather and exposure groups. One interesting observation is that in the two observations the group with least exposure has a total of nine subjects who claim their clothing to be inadequate. Almost without exception these men said their clothing was warm but unsatisfactory for the particular tasks they were doing. Cooks thought they should be issued clothing different from that of other personnel. Mechanics claimed their clothing became so filled with grease and dirt that it was no longer warm when worn outside, and also pointed out the great danger of loose arctic clothing catching in moving machinery. Both officers and enlisted men of the Engineer Test Group at Fort Churchill were quite emphatic in their statement that arctic clothing designed for infantrymen is not suited for Engineer personnel. A second important observation is the favorable reversal of opinion among the greatest exposure group in February as compared to December. This occurred even though the mean temperature was lower and the wind chill greater in the month of more favorable report (February). There are two possible explanations: (1) the personnel may have "become accustomed to the cold" (acclimatization--?), more likely so since they had just experienced the coldest month (January); (2) subjects had learned to wear and use their clothing for maximum warmth and comfort. Both statements are supported by the observation that the majority of subjects tend to wear less clothing after several weeks in the Arctic, even though weather conditions may have become more severe.

The following is a summary of the replies to the two questionnaires in relation to the best (most liked) and worst (most disliked) features of arctic clothing issued to test subjects. Numbers indicate frequency of mention by eighty subjects polled in December 1946 and February 1947.

Best Features

Cap, field, pile, OD--very warm, comfortable, convenient	45
Jacket, field, pile--quite warm for its size and weight	38
Overcoat, parka type--warmest and best all-around outer garment	33
Boot, mukluk--warmest of all footwear	21
Trousers, field, cotton, OD--effective as a windbreak and adds much warmth	19
Shoepacs--best all-around footwear for general use	16
Mittens, arctic--warmest of all handwear issued	14

Worst Features

Overcoat, parka type--hood is not long enough and needs fur for face protection	61
Boot, mukluk--unsatisfactory because (1) too little traction, (2) no arch support, (3) will not hold shape	78
Boot, Blucher, high top--are (1) very cold, (2) have insufficient traction	38
Mittens, arctic--so bulky and clumsy that use of hands is impaired	25

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TABLE 4

ADEQUACY OF CLOTHING IN RELATION TO WEATHER AND DEGREE OF EXPOSURE.

	NUMBER SUBJECTS	HOURS EXPOSURE[1]	ADEQUACY OF CLOTHING			
			YES	PER-CENT	NO	PER-CENT
DECEMBER 1946	MEAN TEMPERATURE = −7.2 °F. MEAN WIND CHILL[2] = 1670					
GROUP I	26	0.5	21	80.8 %	5	19.2 %
GROUP II	27	4.4	18	66.7 %	9	33.3 %
GROUP III	27	7.9	10	37.0 %	17	63.0 %
TOTAL GROUP	80	4.3	49	61.3 %	31	38.7 %
FEBRUARY 1947	MEAN TEMPERATURE = −14 °F. MEAN WIND CHILL[2] = 1785					
GROUP I	26	0.9	22	84.6 %	4	15.4 %
GROUP II	26	4.1	16	61.5 %	10	38.5 %
GROUP III	25	7.3	17	68.0 %	8	32.0 %
TOTAL GROUP	77	4.1	55	71.4 %	22	28.6 %

[1] – HOURS EXPOSURE ARE AVERAGE HOURS OUTSIDE DAILY.

[2] – WIND CHILL VALUES ARE KILOGRAM CALORIES PER SQUARE METER PER HOUR.

Gloves, shell and insert—cold and afford little protection to hands	25
Jacket, field, pile—should have a zipper type opening	16
Overcoat, parka type—is too bulky for many types of jobs	15
Shoepacs—frost up very badly when worn all day	12

The above subjective data obtained through questionnaires are supported by the following observations in the field. Of approximately 100 cases of first and second degree frostbite observed during five months at Fort Churchill all but five involved the face or ears only. Frostbite of the head region decreased as subjects individually altered their parka hoods by lengthening same and/or addition of fur. Forty-five per cent of all subjective complaints concerned footwear. Almost all foot complaints (painful arches, sore ankles, sore leg muscles) encountered by the Medical Officer occurred during the first two weeks that subjects wore the mukluk boot. Test subjects attributed the above symptoms to the wearing of a very flexible footgear without arch support. Also frequently found at morning Sick Call were minor injuries from falls on ice or snow which subjects attributed to insufficient traction of footwear. Many overcame this problem by sewing heavy cord in a zig-zag pattern on the soles of their mukluks.

Fifty enlisted men wore the overcoat type parka (overcoat, parka type) throughout the months of December and January at Fort Churchill, Canada. On the first of February the overcoat type was replaced by the pull-over type parka with fur trimmed hood (parka, field, pile). After one month all subjects were polled as to their preference of the two types, and were asked to list the reasons for their choice. Results of this observation are as follows:

I. Subjects preferring overcoat type parka 30
   1. Easier to take off and on 23
   2. More comfortable 7

II. Subjects preferring pull-over parka 16
   1. Warmer of the two 10
   2. Better face protection 6

III. Subjects having no preference 4

The average outside exposure was slightly higher for the pull-over preference group—4 hours daily as compared to 3 hours for the overcoat preference group. In general those individuals who required maximum protection from the weather preferred the pull-over type parka. However, many of this group stated that they would prefer the overcoat type if hood were lengthened and trimmed with fur for better face protection.

2. Comparison of U. S. Army and Canadian Army Clothing

A careful comparison of Arctic clothing issued by the Canadian Army and by the U. S. Army revealed few differences and little superiority of one type over the other. A good index of the relative merits of the two may be found in the trading of American and Canadian clothing items among soldiers. Most sought-after articles of American clothing were the

the pile-lined field cap and pile-lined field jacket both of which are more desirable than similar articles of Canadian Army issue. Of the many articles of Canadian arctic clothing the string vest and the Canadian Army mukluk proved most popular with American personnel. In this observer's opinion the string vest provides more warmth and comfort for its size and weight than any other clothing item observed, and should be considered for general arctic issue. The Canadian Army mukluk has several features not found in the U. S. Army type: (1) traction type sole, (2) built-in arch support, (3) lace-type instep for more accurate fitting about the foot. Far fewer foot complaints were encountered in those troops equipped with the Canadian type mukluk. Also the Canadian mukluk does not lose its shape or twist around the foot as readily as the U. S. Army type.

C. Conclusions and Recommendations

1. Questionnaires and field observations indicate the need for modification of two clothing items, as follows:

   a. Alteration of parka hoods to provide better protection for the face.

   b. Alteration of footwear to provide greater traction when walking on ice or packed snow.

2. The string vest, providing much additional warmth for a very slight increase in bulk and weight, should be given consideration as a possible item of general arctic issue.

3. Engineer and Signal Corps personnel do not like cold weather clothing designed for infantrymen. In the design of new clothing it appears advisable to give consideration to certain specialized tasks in the Arctic.

4. Excessive bulkiness, tendency to overheating, lack of moisture control, and low acceptability indicate that additional research in new principles and new designs of cold weather clothing is needed. This is particularly true in relation to problems of ventilation and moisture control, as demonstrated by the experiments of Dr. Alan Woodcock at Fort Churchill during the past winter. A report by Dr. Woodcock on his observations is expected shortly.

D. Reference

1. War Department TM10-275. Principles of Cold Weather Clothing and Equipment. (October 1944).

Section IV

OBSERVATIONS ON DIET AND NUTRITION

A. Introduction

An opportunity was available to make some general observations on nutritional requirements of Canadian and U. S. Army personnel living and working at a permanent arctic military installation. A careful record of monthly food consumption, and of average weight change per man was considered the best method under existing conditions. These data were correlated with concurrent weather conditions and amount of outside exposure of test personnel.

In connection with these observations data were obtained concerning the effect of daily vitamin supplements upon resistance to upper respiratory infections.

Subjects used for this nutritional study were 90 Canadian Army and 71 U. S. Army enlisted men permanently stationed at Fort Churchill, Manitoba, Canada. Although observations were conducted only during the months of February and March 1947, all 161 subjects had been at Fort Churchill for at least two months prior to the first observation. Daily exposures ranged from 0 to 8 hours, and activity varied from light work to heavy work. Thus, the picture obtained is not that of any particular exposure or activity group, but one for a normal station complement at a permanent arctic installation.

B. Experimental

1. Nutrition

All food consumed by test personnel came from three sources: (1) meals served at the Army mess, (2) purchases at the local Canteen (Post Exchange), and (3) gift packages mailed from home. No record of the latter is available but it is thought insignificant in view of the extremely poor mail service and the absence of any holiday season during the period of observation.

By means of daily indents (ration receipts) and monthly inventories, records were kept of all food consumed at the mess hall and purchased at the Canteen. Records of the number of individuals fed daily at the mess hall and making purchases at the Canteen were also kept in order to determine the average daily food consumption per man. These data are summarized in Table 5. The values were calculated on a consumption basis, ten per cent having been deducted from mess hall values to allow for preparation and plate wastage. This deduction was decided upon from direct observation and reports of the Mess Sergeant. In addition to the above the following deductions have been made in vitamin values to correct for loss in the cooking process: thiamine 40%; riboflavin 15%; niacin 20%; ascorbic acid 75% (1).

Weight change was used as an index of adequacy of caloric intake. All subjects were weighed on the first day of February, March, April and at the same time of day in each case. Quartermaster portable platform scales,

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TABLE 5

NUTRITION CHART

FORT CHURCHILL, CANADA

(FEBUARY-MARCH 1947)

	FEBRUARY 1947			MARCH 1947		
	MESS[1]	EXTRA[2]	TOTAL	MESS[1]	EXTRA[2]	TOTAL
CALORIES	4071	409	4480	4244	378	4622
PROTEIN (GM.)	123	3	126	128	4	132
FAT (GM.)	191	15	206	201	14	215
CARBOHYDRATE (GM.)	464	63	527	482	59	541
CALCIUM (MG.)	1184	31	1215	1204	30	1234
PHOSPHOROUS (MG.)	2142	?	2142+	2163	?	2163+
IRON (MG.)	21	?	21+	24	?	24+
VITAMIN A (I.U.)	6129	?	6129+	6861	?	6861+
THIAMINE (MG.)	1.48	0.15	1.63	1.62	0.13	1.75
RIBOFLAVIN (MG.)	2.14	0.05	2.19	2.25	0.06	2.31
NIACIN (MG.)	21.1	?	21.1+	21.8	?	21.8+
ASCORBIC ACID (MG.)	82	?	82+	79	?	79+

1 - VALUES ARE AVERAGE FOOD CONSUMPTION PER MAN PER DAY AT THE MESS HALL.

2 - REPRESENTS AVERAGE PURCHASE PER MAN PER DAY AT THE POST EXCHANGE OR CANTEEN.

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previously checked to one quarter pound accuracy, were used for all weight determinations.

Daily weather reports were obtained from the Canadian Government Meteorological Station at Fort Churchill Airport. Mean temperature and mean wind chill values for February and March are given in Table 7. Complete weather data for these months may be found in the section on weather (p.4). Each test subject submitted a personal record of the number of hours of outside exposure daily during the two month observation period.

2. Vitamin Supplements

Observations were made as to the value of supplementary vitamins in increasing resistance to upper respiratory infections. Approximately one half (45 EM) of the U. S. Army personnel were placed on a daily vitamin supplement throughout the months of February and March. This supplement was in the form of a single pill given at the evening meal, and containing the following vitamins: thiamine chloride 3 mg.; riboflavin 3 mg.; pyridoxine hydrochloride 1.5 mg.; pantothenic acid 5 mg.; nicotinamide 25 mg.; ascorbic acid 75 mg.; vitamin A, 10,000 I.U.; vitamin D, 1,000 I. U.

The control group of 40 EM were compared with the vitamin test group as follows: daily sick call and monthly physical examinations for relative incidence of upper respiratory infection, gingivitis, glossitis, or cheilosis. Placebos were not given to the control group.

C. Results and Discussion

1. Nutrition

Nutrition at Fort Churchill during February and March 1947 compares favorably with the recommendations of the National Research Council (1945) for very active personnel (see Table 6). Failure to meet recommended levels is found only in the case of thiamine and riboflavin where there is a deficiency of about 12% in each case.

Comparing the data for February and March (see Table 7), it will be noted that the average outside exposure for each month is three hours daily. The duties and therefore the activities of the test personnel remained essentially the same throughout the period of observation. Thus, with exposure and activity remaining constant, difference in weight gain in February and March is due to two factors--caloric consumption and environmental temperature. For example, February with 140 calories less food consumption daily and 15 degrees lower environmental temperature shows an average weight gain of 0.1 pounds per man as compared to 0.7 pounds per man for March. The average gain of 0.1 pound during February is barely adequate for normal growth and development of personnel whose average age is 22 years. Weight gain during March is more than adequate. These observations indicate that the ration scale for a station complement at a permanent arctic installation should provide a minimum caloric intake of approximately 4500 calories per man per day throughout the winter months.

2. Vitamin Supplements

Comparison of the vitamin test group with the control group reveals no objective findings to support the use of supplementary vitamins to in-

TABLE 6

COMPARISON OF NUTRITION AT FORT CHURCHILL, CANADA WITH NATIONAL RESEARCH COUNCIL RECOMMENDATION

	FORT CHURCHILL, CANADA		NATIONAL RESEARCH COUNCIL (1945)	
	FEBRUARY 1947	MARCH 1947	VERY ACTIVE	MODERATELY ACTIVE
CALORIES	4480	4622	4500	3000
CALCIUM	1215	1234	800	800
IRON	21 +	24 +	12	12
VITAMIN A[1]	6129+	6861 +	5000	5000
THIAMINE	1.63	1.75	2.00	1.50
RIBOFLAVIN	2.19	2.31	2.60	2.00
NIACIN	21.1 +	21.8+	20	15
ASCORBIC ACID	82 +	79 +	75	75

1- VITAMIN A EXPRESSED IN I.U. (INTERNATIONAL UNITS)

- ALL OTHER VALUES ARE MILLIGRAMS.

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TABLE 7

CORRELATION OF NUTRITION, WEATHER, EXPOSURE, AND WEIGHT CHANGE.

	FEBRUARY 1947	MARCH 1947
NUTRITION (DAILY)—		
TOTAL CALORIES	4480	4622
PROTEIN (GM.)	126	132
FAT (GM.)	206	215
CARBOHYDRATE (GM.)	527	541
WEATHER DATA —		
MEAN TEMPERATURE (°F)	−14.0	+0.7
MEAN WIND CHILL[1]	1785	1578
DAILY EXPOSURE (HRS.)	3.1	3.0
WEIGHT CHANGE –		
SUBJECTS	161	144
WEIGHT GAIN (LBS.)	0.1	0.7

1 – WIND CHILL VALUES ARE KILOGRAM CALORIES PER SQUARE METER PER HOUR.

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increase resistance to upper respiratory infections. In the months of February and March there were two cases of acute coryza, one in the test group and one in the control group. At no time could there be detected any gingivitis, glossitis, cheilosis, or other clinical evidence of vitamin deficiency in either group. The above is in agreement with the findings under other experimental conditions of Glickman, Keeton, Mitchell, and Fahnestock (2) who concluded that "the ability of men to withstand the damaging effects of repeated exposure to cooling environments cannot be appreciably enhanced by giving excessive doses of ascorbic acid, thiamine, riboflavin, and nicotinic acid above the amounts required for adequate nutrition."

D. Conclusions and Recommendations

1. This observation indicates that the winter ration scale for an average station complement at a permanent arctic military installation should provide for a minimum consumption of about 4500 calories per man daily.

2. Personnel who are continually exposed to an arctic environment probably require a caloric intake greater than 4500 calories.

3. Limited observations under these conditions failed to show any value of vitamin supplements in the Arctic when the normal diet conforms to the recommended dietary allowances of the National Research Council (1).

E. References:

1. Food Nutrition Board. Recommended dietary allowances. National Research Council, Reprint and Circular No. 122, p. 10 (1945).

2. Glickman, N., R. W. Keeton, H. H. Mitchell, and M. K. Fahnestock. The tolerance of man to cold as affected by dietary modifications: high versus low intake of certain water-soluble vitamins. Am. J. Physiol., 146, 538-558 (1946).

3. Johnson, R. E. and R. M. Kark. Environment and caloric requiremets. Fed. Proc., 6, 138 (1947).

4. Lusk, G. The elements of the science of nutrition, Saunders, Philadelphia, 1928.

5. McLester, J. S. Nutrition and diet in health and disease. Saunders, Philadelphia, 1931.

Section V

OBSERVATIONS ON COFFEE, BEER, AND CIGARETTE CONSUMPTION RELATIONSHIP TO TREMOR AND REACTION TIME

A. Introduction

Three commonly used drugs which may exert considerable influence on normal physiological processes are caffeine (coffee and tea), alcohol (beer) and nicotine (cigarettes). Indications for a study of the effect of a sudden change to an arctic environment upon consumption of the above appeared when five enlisted men reported to the Medical Officer complaining of nervousness, tremor, insomnia, and irritability. Medical histories revealed that all five were consuming at the time 6 to 9 cups of coffee daily as compared to 1 or 2 cups daily before coming to Fort Churchill. Thus, their symptoms may have been due to their sudden increase in caffeine intake. It was decided to make some observations as to the change in coffee, beer, and cigarette consumption when a representative military unit is transferred from a temperate climate (United States) to an arctic climate (Fort Churchill, Canada). Experiments were conducted to determine if any correlation existed between consumption of coffee, beer, or cigarettes and reaction time or tremor.

B. Experimental

During the first week of December 1946, approximately two weeks after arrival in an arctic environment, 68 enlisted personnel submitted the following information--(1) estimated daily consumption of coffee, beer, and cigarettes in the United States just prior to transferring to Fort Churchill, and (2) a record for one week of each day's coffee, beer, and cigarette consumption at Fort Churchill. The latter observations were repeated in February 1947 for evidence of any change after living for three months in an extremely cold climate.

The Simple Visual Discrimination Reaction Time Test, as devised by Horvath and Freedman (1), was performed by each of the 68 subjects. The test involved (1) response to a visual stimulus (lighting of one or both of two neon tubes), (2) a mental decision (choice of three possibilities), and (3) a muscular movement (six inches distance). A Standard Electric Time Clock recorded the reaction time in 1/100ths of seconds. Each subject was given twelve trials and the average used to indicate performance. These results were obtained in February 1947 at the same time as the coffee, beer, and cigarette consumption data reported for the third month in Table 8.

Tremor of the test subjects was measured at the time of the above observations. This was done by use of an apparatus consisting of a wire probe inserted into a target hole, duration of various contacts between probe and periphery of hole being totaled by a Standard Time Clock. The probe is clamped over the front sight of a Colt automatic pistol, and while subject is standing in firing position (arm elevated and straight), is inserted into a target hole of 0.4 cm. diameter. The subject is instructed prior to test that any unsteadiness or wavering of the pistol resulting in contact between probe and target periphery records as an error against him. During a 30-second test period the Standard Time Clock records in 1/100ths of seconds

TREMOR TESTING APPARATUS USED
IN CAFFEINE STUDIES

TREMOR TESTING APPARATUS IN OPERATION

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REACTION TIME TESTING APPARATUS
USED IN CAFFEINE STUDIES

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TABLE 8

COFFEE, TEA, BEER, AND TOBACCO CONSUMPTION IN ARCTIC AND TEMPERATE CLIMATES

DRUG	TEMPERATE CLIMATE	ARCTIC CLIMATE			
		FIRST MONTH		THIRD MONTH	
		AMOUNT	CHANGE[1]	AMOUNT	CHANGE[1]
COFFEE & TEA —					
CUPS (160cc.)	3.1	6.9		6.3	
CAFFEINE (MG.)[2]	496	1104	+ 123 %	1008	+ 103 %
BEER —					
BOTTLES (12 OZ.)	1.3	1.2		1.3	
ALCOHOL (CC.)[3]	14.0	14.6	+ 4.3 %	15.9	+ 13.6 %
TOBACCO —					
CIGARETTES	17.9	16.5		16.9	
NICOTINE (MG.)[2]	125	116	− 7.2 %	118	− 5.6 %

1 – CHANGE IN EACH CASE IS CALCULATED AS PERCENT AGAINST CONSUMPTION IN TEMPERATE CLIMATE.

2 – VALUES ESTIMATED ON BASIS OR 1 MG. CAFFEINE PER CC. COFFEE OR TEA, AND 7 MG. NICOTINE PER CIGARETTE.

3 – CANADIAN BEER CONTAINS 2 3/4 % ALCOHOL BY WEIGHT; US ARMY BEER 3% ALCOHOL BY VOLUME.

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the total time that, due to nervousness or tremor, the probe makes contact with the target plate. The lower score indicates the better performance.

C. Discussion of Results

Table 8 summarizes the results obtained from questionnaires concerning coffee, tea, beer, and cigarette consumption in arctic and temperate climates. It will be noted that the only significant change occurred in coffee and tea intake which increased 123% (3.1 cups to 6.9 cups) during the first month in an arctic environment. After three months coffee and tea consumption had decreased slightly, being 105% greater than the amount used in a temperate climate. Among factors responsible for this sudden increase in coffee and tea intake are the following: (1) desire for hot beverages in a very cold environment; (2) constant availability of free coffee at Fort Churchill; (3) relative unavailability of beverages other than coffee during period covered by these observations. Beer and cigarette consumption were almost identical in temperate and arctic climates. The conversion values to caffeine, alcohol, and nicotine used in Table 8 were obtained from Goodman and Gilman (2).

The reaction time and tremor test scores are compared with coffee, beer, and cigarette consumption in figures 1, 2, and 3. There is no apparent correlation between steadiness or reaction time and the amount of coffee, beer, or cigarettes consumed. However, as may be seen in Fig. 1, there are no very poor steadiness performances among the subjects consuming less than 4 cups of coffee daily, and the poorest performances observed (more than 4 seconds) were made by subjects consuming 5 or more cups of coffee. On the other hand, subjects consuming more than 10 cups performed very well. There is a possibility that the poor performances are made by subjects who are abnormally sensitive to coffee, and who, because of unpleasant symptoms, voluntarily limit their consumption of coffee to less than 10 cups daily. Fig. 1 also indicates the validity of the tremor test scores: all five subjects who complained at Sick Call of "nervousness" had very poor scores of 6 seconds or more. This group represents 7% or more of the group of 68 subjects and therefore experiments designed to demonstrate relative sensitivities of troops to coffee are indicated.

D. Conclusions

1. Coffee and tea consumption increased 123% when 68 enlisted men were transferred from a temperate climate (United States) to an arctic climate (Fort Churchill, Canada). Beer and cigarette consumption was essentially the same in the two environments.

2. There was no apparent correlation of tremor or reaction time with the amount of coffee, beer, or cigarette consumed.

3. Five subjects (7% of the total observed) showed clinical symptoms (nervousness, tremor, insomnia) and "steadiness scores" suggestive of high sensitivity to caffeine-containing beverages.

E. References:

1. Horvath, S. M., and Freedman, A.--Cold Weather Operations. Sub-Project No. 1-11, Influence of Cold Upon the Efficiency of Personnel. AMRL, Fort Knox, Ky. (May 1944).

References (Cont'd)

[illegible] Goodman, L., and Gilman, A.: The Pharmacological Basis of Therapeutics. New York, Macmillan, 1941.

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FIG 1

GRAPH SHOWING RELATION OF COFFEE AND TEA CONSUMPTION TO REACTION TIME AND TREMOR. (CIRCLED POINTS DESIGNATE SUBJECTS COMPLAINING OF NERVOUSNESS, TREMOR, OR INSOMNIA)

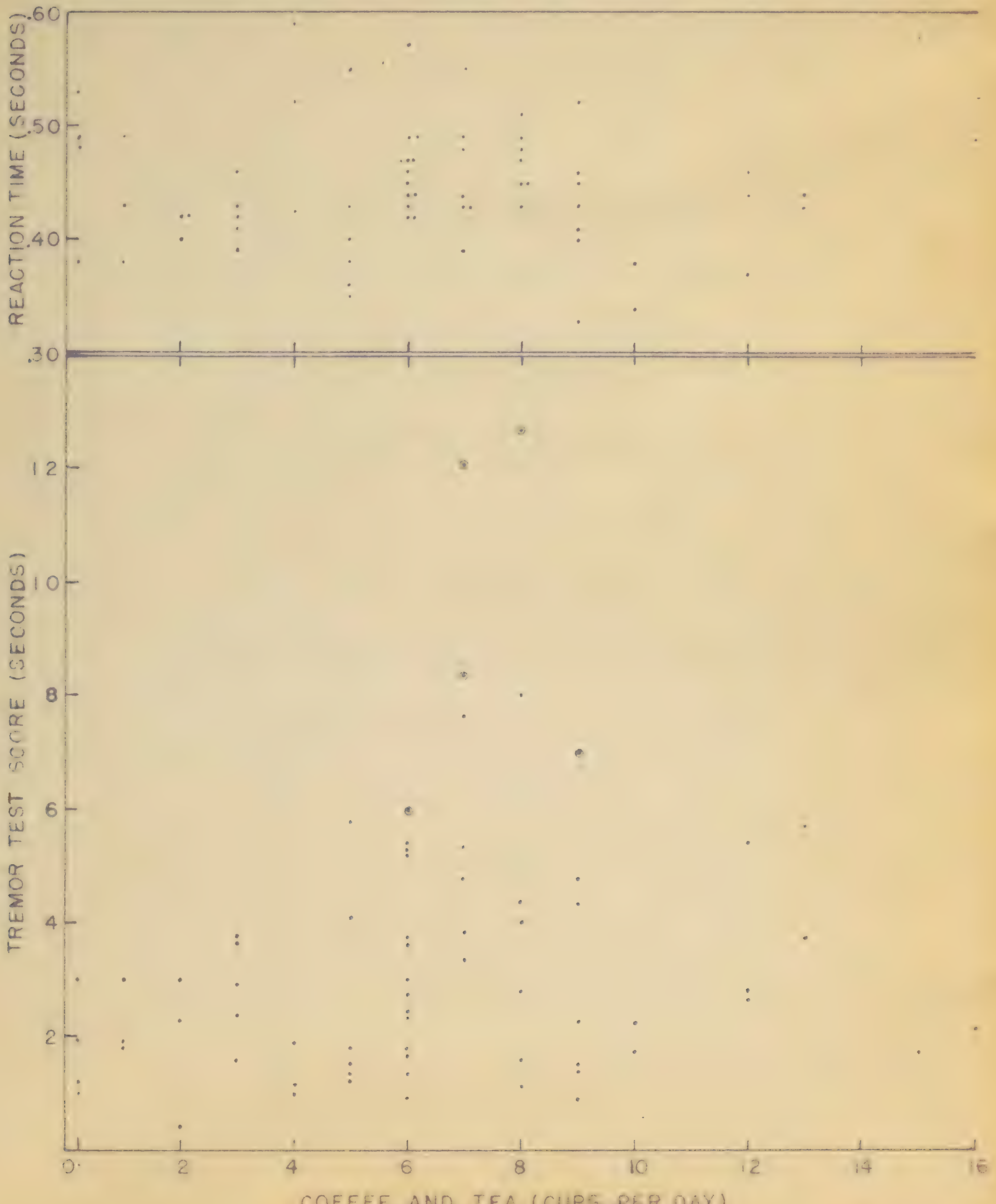

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FIG. 2

GRAPH SHOWING RELATION OF BEER CONSUMPTION TO REACTION TIME AND TREMOR (CIRCLED POINTS DESIGNATE SUBJECTS COMPLAINING OF NERVOUSNESS, TREMOR, OR INSOMNIA)

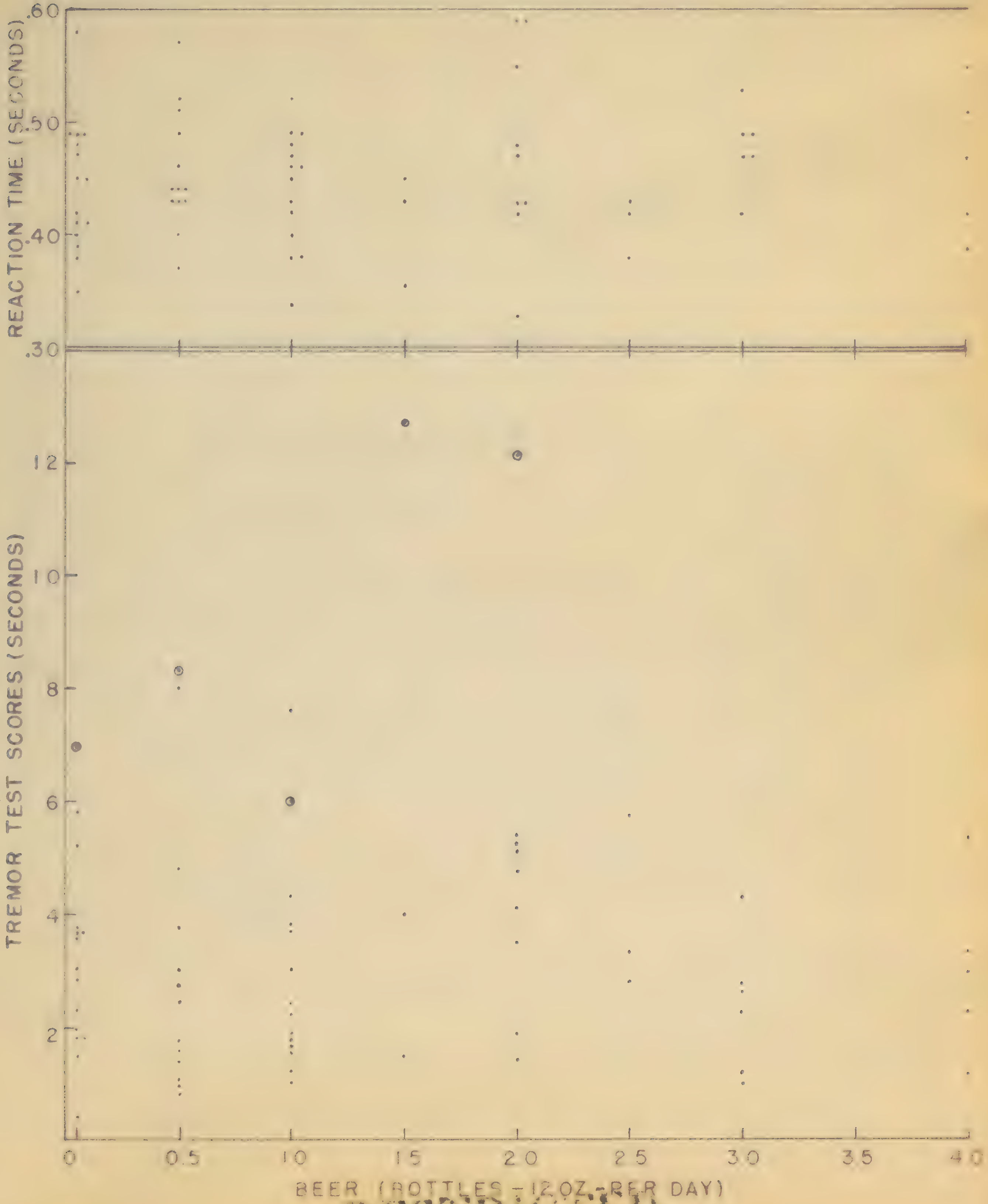

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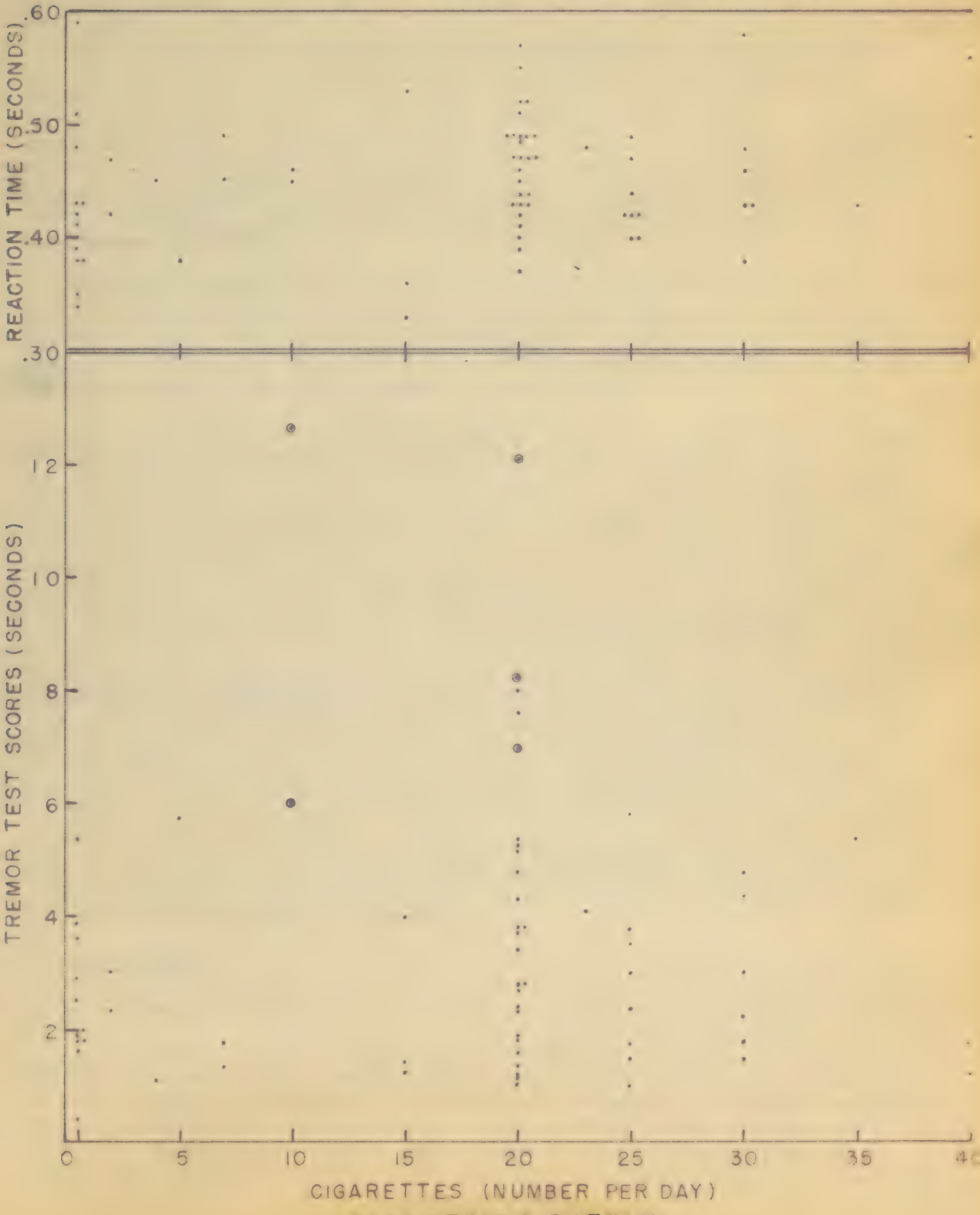
FIG. 3

GRAPH SHOWING RELATION OF CIGARETTE CONSUMPTION TO REACTION TIME AND TREMOR. (CIRCLED POINTS DESIGNATE SUBJECTS COMPLAINING OF NERVOUSNESS, TREMOR, OR INSOMNIA.)



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Section VI

OBSERVATIONS IN THE USE OF ANHIDROTIC FOOT POWDERS

A. Introduction

One of the major problems in an arctic environment is that of keeping the feet warm and protected from the cold. This is largely due to the marked tendency of feet to sweat, especially under conditions of physical exercise or mental stress. This sweat permeates socks, insoles, and shoes to greatly reduce insulation against cold. Thus, the problem is chiefly one of moisture control—this may be attempted in either of two ways: (1) use of a moisture barrier between foot and insulating socks; (2) use of sweat suppressing agents (anhidrotics). It is with the latter method that this observation is concerned.

Numerous sweat suppressing agents are available for test purposes. Anhidrotics most commonly employed are (in order of increasing anhidrotic action): (1) potassium permanganate solution; (2) tannic acid (5% solution); (3) formaldehyde (1-5% solution); (4) aluminum salts (sulfates and chlorides). The aluminum salts are used chiefly in these studies.

In the selection of an anhidrotic agent to be used under conditions of extreme cold the following requirements should be considered: (1) it must be in a form satisfactory for field use under conditions of extreme cold—thus, liquids and ointments are likely to be unsatisfactory because of freezing; (2) it must be in a form quickly and easily applied by troops in the field to their own feet; (3) it must have no deleterious effect on skin, foot, or footwear after prolonged use. A powder is the form of anhidrotic most likely to fulfill the above requirements. Therefore, our sweat suppression studies have been limited to the use of powders as anhidrotic agents.

These studies are intended to obtain knowledge concerning five objectives, as follows: (1) determination of the maximal amount of sweat suppression producible by each of several anhidrotic powder combinations; (2) determination of tolerance of test subjects to various anhidrotic agents employed; (3) determination of the residual effect after a period of non-treatment; (4) record of the subjective symptoms of test personnel exposed to cold as to relative warmth of control (untreated) and test (treated) feet; (5) objective data on skin temperatures of treated and untreated feet as recorded by means of thermocouples. The first three objectives were studied at Fort Churchill during the winter of 1946-47; it is planned to complete the observation during the winter of 1947-48.

B. Experimental

1. Footwear Assembly

A standard footwear combination was adopted for use in all tests, as follows: (1) sock, wool, cushion sole (next to skin); (2) sock, wool, ski; (3) felt insole; (4) shoepac. The shoepac was selected as the best footgear for these observations because (1) it is waterproof, thus permitting the collection and weighing of moisture produced by the foot during the test period, and (2) if the moisture control problem is solved then the impermeable

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shoepac may become a very satisfactory footwear for general wear in extreme cold.

2. Anhidrotic Foot Powders

The foot powder combinations used in these studies were selected and prepared as a result of consultations with several dermatologists. Results of the use of the following powders are reported in this section:

Anhidrotic foot powder No. I: aluminum chloride 3%; salicylic acid 3%; potassium alum 10%; powdered talc 84%.

Anhidrotic foot powder No. II: aluminum chloride 5%; salicylic acid 5%; potassium alum 15%; powdered talc 75%.

Anhidrotic foot powder No. III: aluminum chloride 10%; salicylic acid 5%; potassium alum 20%; powdered talc 65%.

Anhidrotic foot powder No. V: aluminum chloride 5%; boric acid 7%; potassium alum 10%; salicylic acid 3%; starch 5%; powdered talc 70%.

3. Method and Procedure

Each anhidrotic foot powder was tested for one week, daily observations lasting 12 hours—usually from 0900 to 2100. Prior to each test all footwear was dried to a constant weight by means of hot air circulated by blowers. The right cushion sole sock was impregnated with test powder and all footwear weighed at beginning of each observation. Sock and insole combination to be worn on each foot was weighed in a moisture-proof weighing bag; shoepacs weighed separately. All weights were determined to the nearest 0.1 gram.

In each observation the right foot was treated with the anhidrotic powder; the left foot remained untreated as a control. At the conclusion of each daily experiment the outside of the shoepac was wiped free of all dirt and melted snow. Then the footwear was removed and weighed. The increase in weight was used to determine the sweat production. By comparison of moisture contents of footgear of the treated foot with that of the untreated, per cent sweat suppression was determined for each anhidrotic powder.

Following each daily observation the feet were carefully examined for the presence of any rash, peeling, dermatitis, or other evidence that might indicate intolerance to the strength of powder used.

It was noted that, following treatment with each powder, there was considerable residual effect. Therefore, after 16 days of no tests or observations, the experiment was repeated with both feet untreated, and the residual effect of previous tests determined.

C. Discussion

1. Anhidrotic Action

Table 9 gives a summary of the results on the three subjects observed. The results given for each powder are the average of five observations of

SWEAT SUPPRESSING POWDERS USED
IN FOOT EXPERIMENTS

FOOTWEAR COMBINATION WITH WEIGHING BAG

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twelve hours' duration each on five consecutive days. Sweat suppression by the various anhidrotic combinations ranged from 5% to 25%. There was considerable variation in the anhidrotic effect of any one of the several combinations tested. Among the subjects observed the one with greatest sweat production experienced greatest anhidrotic action in 60% of all tests. Dermatological consultants had previously suggested that maximum sweat suppression would be found in those subjects with hyperhidrosis. The wide variations in moisture production by the control foot of a single subject are attributed to variations in both activity and ambient temperatures, neither of which was controlled in this experiment. Observations suggest that the anhidrotic effect is a cumulative one, and that maximum sweat suppression by any one agent is probably attained only by repeated applications. This factor of summation of effect has not been controlled in comparison of the anhidrotic action of different powders.

2. Tolerance

All subjects had a slight reaction to foot powder No. III containing 10% aluminum chloride and 20% potassium alum. Two subjects developed a very small area (2-3 cm. in diameter) of skin rash which cleared up when use of the powder ceased. The third subject experienced superficial peeling of the sole of the treated foot. No ill effects of any kind were observed from use of powders containing 5% or less aluminum chloride and 15% or less potassium alum. Since the anhidrotic effect appears to be cumulative a powder containing 3% aluminum chloride and 10% potassium alum might possibly be adequate to give maximum sweat suppression after repeated treatments. Also, such a powder would appear to be well within the range of tolerance, but observations on a much larger group of subjects would be necessary to definitely establish it's safety.

3. Residual Effect

After 16 days without treatment approximately 60% of the sweat suppressing effect of the previous anhidrotic treatments still remains. Those subjects with greater sweating retain the greater residual effect. This may be of significance and value in those individuals with hyperhidrosis who have greatest difficulty in keeping their feet warm and protected in extreme cold.

D. Conclusions and Recommendations

1. The maximum average sweat suppression produced in one subject by any of the anhidrotic agents employed in this observation was 25%.

2. All three subjects tolerated well anhidrotic agents containing 5% or less aluminum chloride and 15% or less potassium alum. Each subject experienced an unfavorable reaction to a powder containing 10% aluminum chloride and 20% potassium alum.

3. A residual effect of 60% was still present 16 days after the last anhidrotic treatment.

4. No ill effects on socks, insoles, or shoepacs were observed from any of the anhidrotic powders tested.

TABLE 9

SWEAT SUPPRESSION BY ANHIDROTIC FOOT POWDERS.

(SWEAT EXPRESSED AS WATER IN GRAMS)

	FOOT POWDERS					NO TREATMENT
	I[1]	II[2]	III[3]	V[4]		
SUBJECT A—					16 DAYS OF NO TESTING.	
LEFT FOOT (CONTROL)	57.8	69.0	57.0	56.1		45.4
RIGHT FOOT (TREATED)	52.9	60.6	46.4	49.3		41.9
SWEAT DECREASED	4.9	8.4	10.6	6.8		3.5
PERCENT DECREASE	8.5%	12.2%	18.6%	12.2%		7.7%
SUBJECT B—						
LEFT FOOT (CONTROL)	62.2	65.0	52.0	42.7		43.3
RIGHT FOOT (TREATED)	57.6	57.5	44.5	40.9		42.1
SWEAT DECREASED	4.6	7.5	7.5	1.8		1.2
PERCENT DECREASE	7.4%	11.5%	14.4%	4.2%		2.8%
SUBJECT C—						
LEFT FOOT (CONTROL)	63.0	79.7	59.0	58.4		58.3
RIGHT FOOT (TREATED)	54.9	72.5	48.6	44.3		50.6
SWEAT DECREASED	8.1	7.2	10.4	14.1		7.7
PERCENT DECREASE	12.8%	9.0%	17.6%	24.2%		13.2%
AVERAGE—						
LEFT FOOT (CONTROL)	61.0	71.2	56.0	52.4		49.0
RIGHT FOOT (TREATED)	55.1	63.5	46.5	44.8		44.9
SWEAT DECREASED	5.9	7.7	9.5	7.6		4.1
PERCENT DECREASE	9.6%	10.8%	17.0%	14.4%		8.4%

[1] — ALUMINUM CHLORIDE - 3%; SALICYLIC ACID - 3%; POTASSIUM ALUM - 10%; POWDERED TALC - 84%.

[2] — ALUMINUM CHLORIDE - 5%; SALICYLIC ACID - 5%; POTASSIUM ALUM - 15%; POWDERED TALC - 75%.

[3] — ALUMINUM CHLORIDE - 10%; SALICYLIC ACID - 5%; POTASSIUM ALUM - 20%, POWDERED TALC - 65%.

[4] — ALUMINUM CHLORIDE - 5%; BORIC ACID - 7%; POTASSIUM ALUM - 10%; SALICYLIC ACID - 3%; STARCH - 5%; POWDERED TALC - 70%

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5. It is recommended that these studies be continued during the winter of 1947-48, carefully controlling the activity and exposure of test subjects, and recording skin temperatures of treated and untreated feet.

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Section VII

OBSERVATIONS ON PSYCHOLOGY AND MORALE OF TROOPS IN AN ARCTIC ENVIRONMENT

Questionnaires for the purpose of studying the morale situation and the psychological adjustment of troops stationed in an arctic environment were prepared by Captain Moody C. Bettis, M. C., and Mr. Daniel I. Malamud, Psychologist, Department of Psychiatry and Sociology, Branch United States Disciplinary Barracks, Fort Knox, Ky. In February 1947 personnel of the Medical Department Field Research Laboratory submitted these questionnaires to 78 U. S. Army enlisted men stationed at Fort Churchill, Canada since November 1946. All subjects signed their names to the answer sheets so that data on age, Army General Classification Test Scores, and education could be obtained from their service records. Questionnaires and tabulated answers are presented below.

ATTITUDE QUESTIONNAIRE

We are studying the effects of extremely cold climate and limited environmental conditions on the morale, efficiency and health of enlisted men. We are as interested in adjusting men to this climate as we are in adjusting equipment. You can help us greatly in this project by answering the following questionnaire as frankly and fully as possible. Only by letting us know your own personal reactions, can we hope to grasp the problems involved in your adjustment and the necessary steps to be taken for their solution. Use separate sheets for your answers and number each answer carefully.

		YES	NO
1.	Were you used to cold weather on arrival?	34	44
2.	Do you like winter sports?	56	22
3.	Are you used to cold weather now?	55	23
4.	Did you volunteer for this assignment?	15	63
5.	Did you find the work situation that you expected?	37	33
6.	Are you satisfied with the work situation?	45	31
7.	Did you find the housing as you expected?	12	38
8.	Are you satisfied with the housing conditions?	33	43
9.	Are you satisfied with the meals here?	13	62
10.	Do you get enough to eat?	34	44
11.	Do you like the type of food you get?	17	60
12.	Do you have a good appetite?	65	10
13.	Have you noticed any change in your food likes or dislikes?	17	57
14.	Do you find yourself in need of something to do in your spare time?	59	17
15.	Are recreational facilities adequate?	4	70
16.	Do you like to visit nearby villages?	21	56
17.	Are the hardships of this climate frequently discussed?	55	23
18.	Are you interested in your work?	[illegible]	15
19.	Do you feel that officers or associates have it "in for you"?	4	74
20.	Are your officers tolerant and understanding?	63	7
21.	Have you noticed any change in your reasoning power?	19	56

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ATTITUDE QUESTIONNAIRE (Cont'd)

		YES	NO
22.	Have you noticed any change in your memory?	21	57
23.	Are you restless?	56	22
24.	Are you irritable?	50	27
25.	Are you apprehensive?	36	35
26.	Do you have any trouble sleeping?	19	58
27.	Do you have any dreams or nightmares?	44	32
28.	Have you noticed any change in your drive or enthusiasm?	23	48
29.	Are you afraid of getting lost?	6	72
30	Do you get lost easily?	12	66
31.	Have you ever been lost?	22	56
32.	Do you feel that you would be found if you were to get lost?	49	21
33.	Do you frequently get lost in this climate?	1	75
34.	Do you take adequate precautions to dress properly?	69	9
35.	Do you feel that this climate is dangerous to life and health?	32	43
36.	Would you say that the majority have the same attitude as you concerning this experiment?	61	5
37.	Is sex a problem with you?	40	31
38.	Have you been able to find sex gratification at nearby villages?	1	71
39.	Do you go on sick call?	22	55
40.	Do you like the drinking water?	26	50
41.	Do you feel that the work you are doing is important?	48	28
42.	Do you feel that you have been given sufficient credit for the work you are doing?	48	25
43.	Do you object to this questionnaire?	17	38

OPINION POLL

INSTRUCTIONS: These are questions about how you have changed since you have been in this unit. Check each one.

		MORE	LESS	NO CHANGE
1.	Do you feel that you have become more ambitious, or less ambitious?	9	33	36
2.	Are you inclined to be more moody, or less moody?	36	15	26
3.	Have you felt more thwarted or held down than before, or less so?	31	21	22
4.	Since coming into this unit are you inclined to be more cheerful, or less cheerful?	18	34	24
5.	Have your experiences made you more hardboiled in your attitude toward others, or less hardboiled?	30	13	34

OPINION POLL (Cont'd)

		MORE	LESS	NO CHANGE
6.	Do you feel more regretful and sorry about things that have happened to you, or do you feel less sorry?	20	16	42
7.	Do you tend to get angry more easily than you did before, or less easily?	48	11	19
8.	Are you more self-confident since coming into this unit, or less self-confident	42	8	28
9.	Are you inclined to be more disgusted with things in general or less so?	52	6	20
10.	Do you tend to be more optimistic in your viewpoints, or less optimistic?	26	17	35
11.	Do you feel that your life in this unit has made you more satisfied or less satisfied?	20	30	28
12.	Are you more happy, or less happy?	9	52	17
13.	Are you more restless, or less restless?	50	7	21
14.	Have you become more sociable, or less sociable?	34	18	26
15.	Do you feel more able to take responsibility, or less able?	41	9	28
16.	Do you feel more independent or less independent?	38	14	26
17.	Do you feel depressed more often or less often?	39	7	32
18.	Do you feel more tolerant of other people, or less tolerant?	23	21	34
19.	Are you more critical of others, or less critical?	19	12	47
20.	Do you tend to be more easily annoyed by people, or less easily annoyed?	10	7	61
21.	Do you worry more often, or less often?	31	19	28
22.	Do you resent being told what to do more than you did before, or do you resent it less?	16	11	51

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OPINION POLL (Cont'd)

		MORE	LESS	NO CHANGE
23.	Can you concentrate and keep your mind on what you are doing more easily, or less easily?	14	24	40
24.	Do you feel more cooperative toward others, or less cooperative?	34	15	29
25.	Do you criticize yourself more often than you used to, or less often?	25	12	41
26.	Do you have more patience, or less patience?	15	42	21
27.	Do you feel more tense and keyed up more often than you used to or less often?	39	10	29
28.	Do you have more perseverance or are you unable to keep at things you are doing?	19	15	44
29.	Do you have more and wider interests now than you used to have, or are your interests less wide?	33	15	30

Analysis of the questionnaire data, conclusions, and recommendations will be presented in a separate report to be submitted by Captain Rettis and Mr. [illegible] to the Division of Neuropsychiatry, Office of the Surgeon General.

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Section VIII

RECOMMENDATIONS

A. Recommend that a semi-permanent branch laboratory of the Medical Department Field Research Laboratory be established at Fort Churchill, Manitoba, Canada for the following reasons:

1. Weather

Reports for the past ten years show that Churchill, because of the excessively high wind chill, has winter weather conditions that are among the most severe on the North American continent. Three different weather conditions are available for cold experimentation: (1) extreme cold (-30 F. to -50 F.); (2) severe wind chill (average wind velocity of 15-20 mph but 40-50 mph frequent); (3) blowing snow (visibility at times is less than 10 feet).

2. Accessibility

At Churchill true arctic weather reaches its nearest point to the United States. Chicago is only six (C-54) to eight (C-47) hours easy flying time from Fort Churchill Airport. Bi-weekly railroad service to Churchill is maintained throughout the winter. Harbor facilities permit handling of ocean-going freighters from July until September.

3. Topography

Churchill, located at the northern limit of the evergreen forest and at the boundary between Arctic and sub-Arctic, has three types of terrain easily available for cold weather testing: (1) sub-arctic forest to the south; (2) barren wastelands (tundra, muskeg) to the north; (3) sea-ice of the Hudson Bay a few hundred yards away.

4. Daylight

A minimum of seven to eight hours daylight is present at Churchill throughout the winter—more than are present at any other place with weather of comparable severity. This reduces the problem of insufficient daylight for testing personnel and equipment in the Arctic when weather conditions are most severe.

5. Facilities

Fort Churchill has at present about sixty semi-permanent wooden buildings, the majority of which are in fairly good condition. A completely equipped and fully staffed meteorological station provides daily weather reports and forecasts. Native whites, Indians, and Eskimos are available in the Churchill area as test subjects.

6. Joint Canadian - American Research

Fort Churchill offers an opportunity for joint research with the Canadian Army, and the benefit of their experience in the Arctic.

B. Recommend that the following general types of field research problems be investigated by the Medical Department Field Research Laboratory at Fort Churchill, Canada:

1. Evaluation of physiological changes that occur in troops during arctic operations.

2. Determination of physiological limitations of troops under varied conditions of exposure to arctic winter weather.

3. Development and evaluation of expedients for increasing the resistance of troops to arctic winter weather.

4. Comparison of the physiological responses especially to cold stimulation in different racial groups of men and in different animal strains.

C. Recommend that the following projects be investigated by the Medical Department Field Research Laboratory at Fort Churchill, Canada, during the period 15 October 1947 to 15 April 1948.

1. Comparison of the basal metabolism of white men, Eskimos and Indians during different seasons.

Metabolism studies on troops under basal conditions, using closed circuit indirect methods, throughout the winter in Churchill, should indicate whether changes in basal metabolism are involved in acclimatization to cold. Equipment may be taken to Baker Lake and basal metabolism studies made on Eskimos to determine whether a higher metabolic rate is associated with the apparently greater resistance of Eskimos to cold. In addition, observations may be made at Churchill on Indians and white inhabitants of the area to gain information on comparative basal metabolic rates.

2. Basal cardiovascular measurements and the effect of cold stimulation of the face of white men, Eskimos and Indians.

The cardiovascular observations made in conjunction with basal metabolic studies, would provide information on basal heart rate, rectal and certain skin temperatures, and blood pressure of different racial groups. Changes which might result from acclimatization could also be determined. Similar measurements can be made to determine the reflex cardiovascular responses to a cold stimulus, simulating arctic wind chill, applied to the face.

3. The state of water balance of troops during arctic winter field operations.

Troops in bivouac can be required to perform scheduled activities. The water intake from food and from melted snow, as well as the caloric intake, can be determined for each subject. The state of water balance under these conditions should be indicated by daily observations on each subject of body weight, total water intake including water consumed in food, volume of urine excreted, specific gravity of blood and urine, and indicated chemical analysis of blood and urine for specific substances such as sodium or potassium. Physiological effects of possible dehydration may be evaluated by a modified fitness test, by observation, and by subjective reports of the troops.

4. Cooling rate and tolerance times of resting men protected by army evacuation equipment in arctic winter weather. (In cooperation with Medical Supply Section, Office of the Surgeon General).

The cooling rates of resting troops under conditions employed in evacuation of casualties can be observed by determining changes in skin and rectal temperatures thermoelectrically. Tolerance times will be appreciated from skin and rectal temperatures measurements and the subjective reports of the simulated casualties. Various types of evacuation equipment and techniques can be compared under different environmental conditions. Data obtained will be of value in designing experiments to determine the proper early treatment and best means of evacuation of casualties under arctic winter conditions.

5. Physiological aspects of maintaining the physical condition of troops by rewarming during long exposure to extreme cold.

Methods of rewarming, and the relation of frequency and duration of periods of warming to periods of exposure should be investigated. Direct observation, measurements of skin and rectal temperatures, the subjective reactions of the troops, etc., can be used to indicate the physical and physiological condition of the troops. These studies would permit the selection of means for prolonging the period that troops may endure arctic winter weather.

6. Effectiveness of sweat control measures and their value.

a. Anhidrotic foot powder

Studies reported in Section VI should be continued to determine the maximum anhidrosis which can be obtained with these agents and the effect of activity and environmental temperature on the degree of anhidrosis. The value of the anhidrosis should be determined by comparing, in the same subject, the comfort and skin temperatures of treated and untreated feet.

b. Ventilated and barrier layer clothing (In cooperation with Dr. Alan Woodcock, Canadian Research and Development)

Sweat accumulation in the barrier system of the clothing designed and to be tested by Dr. Woodcock should be measured, and clinical observations made on possible effects on the skin of moisture within the barrier.

Subjective reactions which will be obtained by Dr. Woodcock should be supplemented by a comparison of skin and rectal temperatures resulting from the wearing of the various types of clothing under test.

7. Local vascular and temperature changes in man resulting from frostbite.

As cases of frostbite appear among personnel stationed at Fort Churchill observations will be made as to the relative skin temperatures of normal and affected parts. Studies will also be made on vascular responses in normal and frostbitten areas to certain stimuli (cold, heat). The data obtained may contribute information concerning vascular changes occurring in frostbite.

RESTRICTED

8. Psychological analysis of stress imposed by arctic environments (analysis in cooperation with Division of Neuropsychiatry, Office of the Surgeon General).

The psychological state of the test subjects will greatly influence objective physiological data. Cooperation with psychologists is desirable in designing physiological experiments on man. This laboratory is prepared to obtain field data on psychological problems by means of questionnaires, interviews, and direct observation of personnel at Fort Churchill during the course of other experimental studies.

9. General observation on problems and field expedients in the Arctic. Procurement and training of animals for studies on species differences and effects of arctic environments.

TABLE 10

TENTATIVE SCHEDULE

FORT CHURCHILL, CANADA

(WINTER 1947 - 1948)

RESEARCH PROBLEMS	OCT. 15-31	NOV. 1-15	NOV. 16-30	DEC. 1-15	DEC. 16-31	JAN. 1-15	JAN. 16-31	FEB 1-14	FEB. 15-28	MAR. 1-15	MAR. 16-31	APR 1-15
PREPARATION ON ARRIVAL AND FOR DEPARTURE	X											X
BMR STUDIES ———— (1)		X						X			X	
CARDIOVASCULAR STUDIES —(2)		X						X			X	
WATER BALANCE ———(3)							X			X		
EVACUATION PROBLEM ——(4)					X							
REWARMING EXPERIMENT —(5)						X						
ANHIDROTIC STUDIES ——(6a)	X	X			X			X				
MOISTURE CONTROL ——(6b)			X	X					X			
FROSTBITE ———— (7)						X	X	X	X			
PSYCHOPHYSIOL. PROBLEM.(8)		X					X				X	

RESTRICTED

No 9

APPLICATION OF THE INFRA-RED GAS ANALYZER TO THE STUDY OF HUMAN ENERGY METABOLISM*

by

H. J. Spoor, Capt., M.C., and G. C. Davis, Capt., M.C.

from

Medical Department Field Research Laboratory
Fort Knox, Kentucky, 21 August 1947

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*Sub-Project under Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks. (M.D.F.R.L.-57). Approved by CG, ASF, 31 May 1946.

No. 9

Project No. 57-4
[illegible]

21 August 1947

ABSTRACT

UTILIZATION OF THE INFRA-RED GAS ANALYZER TO THE STUDY OF HUMAN ENERGY METABOLISM

OBJECT

The determination of the caloric expenditure of troops during maneuvers has resolved itself into the establishment of a suitable practical field method for measurement of respiratory changes in man in such physical situations that would not permit the use of existing apparatus. A method was desired which would offer 2 advantages over present field techniques: (1) graphic continuous analytical record over protracted periods rather than period averages for short duration effort, and (2) portable equipment which would measure actual expenditure of a particular activity rather than an additive effect of the exercise plus apparatus load.

RESULTS

A new technique for measurement of caloric expenditure during continuous activity has been developed. Both laboratory and field trials have proved the adaptability of the Leeds and Northrup selective gas analyzer to the estimation of carbon dioxide in expired air. Caloric expenditure studies on men undergoing mountain warfare training have been accomplished. The new method offered instantaneous analysis and continuous records over protracted periods of activity.

CONCLUSIONS

The infra-red analyzer equipped with an adequate pumping system for controlled air flow has been adapted to metabolic work and found satisfactory, both in the laboratory and in the field.

RECOMMENDATIONS

The apparatus developed and tested is satisfactory for routine study of respiratory exchange. To obtain absolute fidelity, i.e. synchronization of recorded response with respiratory excursion, and continuous analytical records of oxygen utilization, should be the aim of subsequent investigation.

Submitted by:
H. J. Spoor, Capt., M.C.
G. C. Davis, Capt., M.C.

Approved Ray G Daggs
RAY G. DAGGS
Director of Research

Approved F J Knoblauch
FREDERICK J. KNOBLAUCH
Lt. Col., M.C.
Commanding

APPLICATION OF THE INFRA-RED GAS ANALYZER TO THE STUDY OF HUMAN ENERGY METABOLISM

I. INTRODUCTION

The problem of caloric expenditure studies on troops engaged in military maneuvers resolved itself into the establishment of a suitable practical field method for determining respiratory changes in man in such physical situations that would not permit the use of bulky apparatus. The method devised offers two advantages over present field techniques: (1) graphic continuous analytical record over protracted periods rather than period averages for short duration effort, and (2) portable equipment which will measure actual expenditure of particular exertion rather than special conditions of simulated exercise plus apparatus load. To obtain these objectives: (1) a Leeds and Northrup infra-red gas analyzer was adapted to quantitative detection of carbon dioxide, (2) continuous graphic data were recorded by an Esterline-Angus microammeter, and (3) portability was simulated by use of the A-13 oxygen demand mask to which was connected a long air line carried by cable and pulley rigging extending to the analysis assembly. The apparatus permitted continuous sampling of air over difficult terrain.

This report concerns itself with (1) the adaptation of the Leeds and Northrup infra-red gas analyzer and associated apparatus to measurement of human energy metabolism in the laboratory and (2) application to field studies of the energy metabolism of troops engaged in mountain warfare training.

II. EXPERIMENTAL

A. Apparatus and Methods

1. Gas Analyzer.

The Leeds and Northrup selective gas analyzer was designed to measure small concentrations of carbon monoxide (1). It has been adapted to quantitation of water vapor (2), and has been sensitized to carbon dioxide (3). The subject instrument is functionally based upon the selective absorption by the gas in question of radiation in the infra-red region of the spectrum (CO 4.7, H_2O 6.0 and CO_2 4.3 microns wave length absorption bands).

A complete technical description of the instrument, with detailed operating instructions has been previously reported (3). A brief description follows: Infra-red radiation is emitted by an electrically heated nichrome coil. The rays pass across a test chamber which contains the gas sample to be analyzed. After leaving the test chamber, the beam of radiation is split into 2 parts by an axially divided filter chamber, and then falls onto 2 thermopile sections. The instrument achieves its selectivity by the fillings of the filter chambers. One of these is filled with the gas under analysis (i.e. CO_2) and the other with non-absorbent gas (i.e. O_2). The oxygen side of the cone does not absorb an appreciable amount of radiation. The carbon dioxide side of the cone absorbs radiation maximally within its absorption bands. Both branches respond identically to non-absorbed radiation. Output of the two thermopiles is balanced. Then, introduction of carbon dioxide into the test chamber causes a change

in thermopile output because absorption decreases the radiation falling upon the oxygen cone thermopile. All foreign components absorb from each chamber equally except for those gases with absorption bands overlapping those of carbon dioxide. Possible effects of carbon monoxide and water vapor are avoided by eliminating these two as contaminants.

2. Expired Air Collection.

For the measurement of carbon dioxide concentration of expired air to be useful as a measure of metabolic expenditure, one of two conditions must be filled. First, the expiratory volume can be measured, from which the carbon dioxide concentration will give the per cent by volume as in the classical Haldane technique; second, the volume flow from the subject can be kept essentially constant by force pumping. Enrichment of this constant volume with carbon dioxide from expired air will permit expression of carbon dioxide as per cent of a flow. From data of this sort carbon dioxide, expelled by the subject for a period, can indicate directly his rate of production, regardless of the actual expired volume.

In this problem, we have utilized the latter principle, namely constant flow from the subject by means of force pumping of air through a large capacity hose leading from mask to machine. A schematic diagram of the assembly is given in Figure 1. An analyzer aliquot was drawn from the main flow line by means of a small constant speed rotary pump. In practice the only limiting factor on maneuverability of the subject in reference to analyzer and recorder was the length of air hose between subject and machine. The limit on this length was the ability to handle the hose mechanically. By use of cable and pulley rigging in the field, up to 400 feet of hose were handled with no more inconvenience to the subject than the usual laboratory mask assembly. In the laboratory during standardization of the apparatus various flow meters, mixing chambers, temperature baths and filtration columns for investigation of factors influencing instrument sensitivity and selectivity were inserted between the subject and the analyzer.

3. Air Flow Rates.

The determination of air flow rates in the main and aliquot circuits was very accurately accomplished because subsequent carbon dioxide concentrations were interpreted as percentage of a constant volume. These flow rates were ascertained in the laboratory by the following standard techniques:

a. Spirometer Calibration.

The laboratory spirometer, 500 liter capacity, was calibrated by filling it from an air compressor through a volumetric gas meter (Precision Scientific Co., Chicago, Ill.) recording liters. Direct measurement of filling volume per centimeter bell rise gave a value of 4.35 liters when corrected to standard conditions.

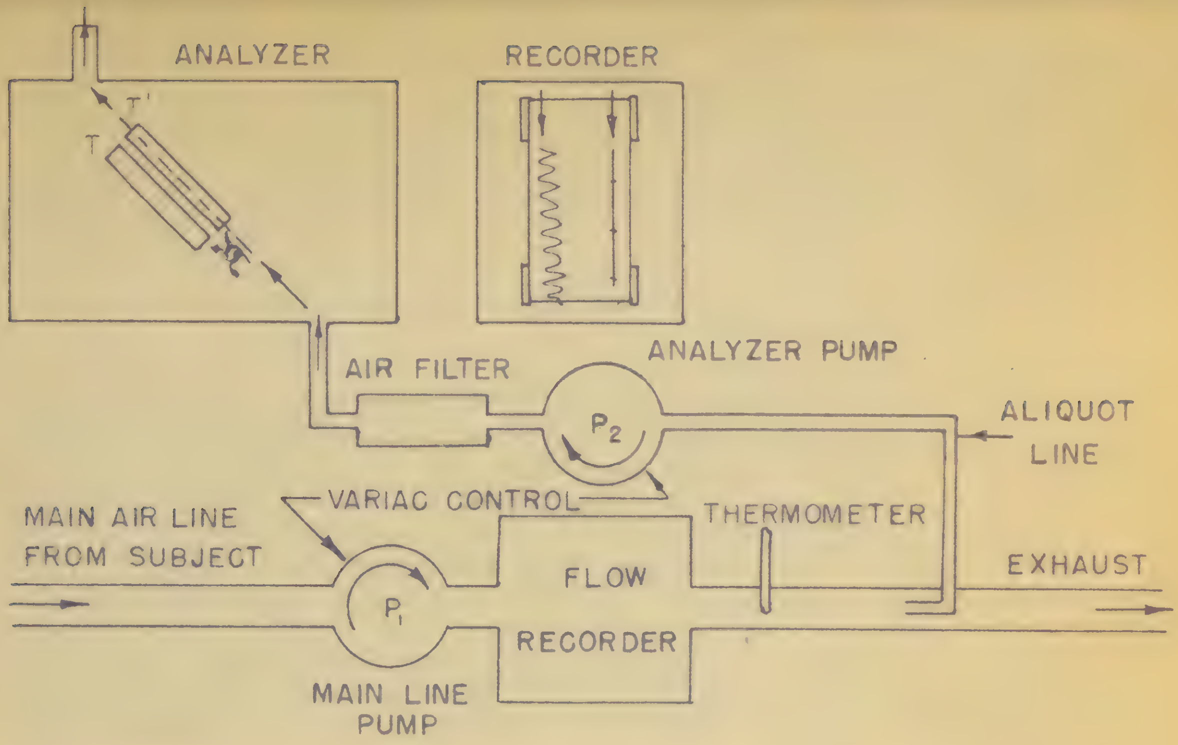


FIG.I. DIAGRAM OF ASSEMBLY

b. Calibration of Main Circuit.

The volume flow of air through the large hose circuit from the subject depended upon the operating speed of the main line pump (P_1 Fig.1). The line flow was calibrated by measuring the rate of air flow at various motor rate control settings against the previously calibrated 500 liter spirometer. Tracings of time against distance (bell elevation) for "variac" settings of 20, 40, 50, 60 and 80 volts were obtained. Values from these curves (i.e. cm./min.) were converted to liters per minute by use of the STP conversion factor for the spirometer, namely 4.35 liters per centimeter rise. Line resistance in the system was induced by two distinct major factors: (1) the mask and man and (2) an orifice flow diaphragm used in conjunction with recording devices. Table 1 summarizes the data obtained. These data compare flow rates under the following conditions: (1) with neither mask, man nor flow meter; (2) with mask alone, without man or meter; (3) with mask and man, but no meter; (4) with meter and mask, without man; (5) with mask, man and orifice flow meter.

TABLE 1

MAIN LINE FLOW
Liters per Minute (STP) at Various Variac Settings

CONDITIONS	20 V	40 V	50 V	60 V	80 V
1	104	261		366	
2	42.8	115		168	
3	31.8	108		164	211
4		91.8	114	137	
5		83.4	102	124	

Condition 5—i.e., with mask, man and orifice flow meter—was that used for subsequent metabolic study. Standard conditions were arbitrarily established as those prevailing at a main line pump variac setting of 50 volts, namely, 102 liters per minute (STP). This volume was greatly in excess of any expiratory volume later obtained from a subject. Calculated volume flow based on the orifice formula (4) agreed with the above experimental values.

c. Calibration of Aliquot Circuit.

The small aliquot circuit leading to the gas analyzer was powered by a constant speed motor air pump designed to deliver about 10 liters of air per minute through the analyzer chamber. To check constancy of flow of this pump, the air stream was calibrated against the spirometer. Current supplied to the pump was regulated by a variac (P_2 Fig. 1), and tracings of volume versus time at various voltage settings recorded. For settings ranging from 40 to 160 volts the flow output varied between 10.02 and 12.00 liters per minute. The motor was designed to operate most efficiently at 120 volts. The air flow rate at this setting was 10.87 liters per minute. This value was used throughout for aliquot line flow. Changes in flow of the main line had no effect on the constancy of the aliquot flow.

4. Standardization of the Selective Gas Analyzer.

After air volume control was established, standardization of the infra-red gas analyzer against known carbon dioxide-oxygen gas mixtures was accomplished. An investigation of the factors influencing receptivity and interpretation accuracy of the instrument was undertaken.

a. Standard Carbon Dioxide Mixtures.

Known mixtures of carbon dioxide and oxygen covering the expected range of carbon dioxide concentration (0 - 5%) to be encountered were prepared. Analysis by the Haldane technique of different cylinders containing gas gave the following compositions: 0.267, 0.549, 1.26, 2.37 and 4.32 per cent carbon dioxide in oxygen. These, with outside air (0.03% CO_2) and pure oxygen, comprised the standard series. Air dilution at the source to 100 liters per minute was enough in excess over expiratory volume to insure analysis within this standard range. The standard gas mixtures were fed directly into the aliquot line to the analyzer. As stated, air flow to the analyzer was supplied at a constant rate of 10.86 liters per minute. Inserted into the air line between the pump (P_2 Fig. 1) and the analyzer was a "charcolite" air filter (Fig. 1). This served three purposes: (1) mechanical filtration of air, (2) removal of water vapor, and (3) removal of charcoal absorbable gases. For testing the effects of water vapor the filter was replaced by suitable apparatus. An initial series of responses of the gas analyzer to the various carbon dioxide mixtures is shown in Figure 2. The Esterline-Angus graphic records read from right to left. Tabulation of the results in terms of average and maximum microvolt deflection is given (Table 2).

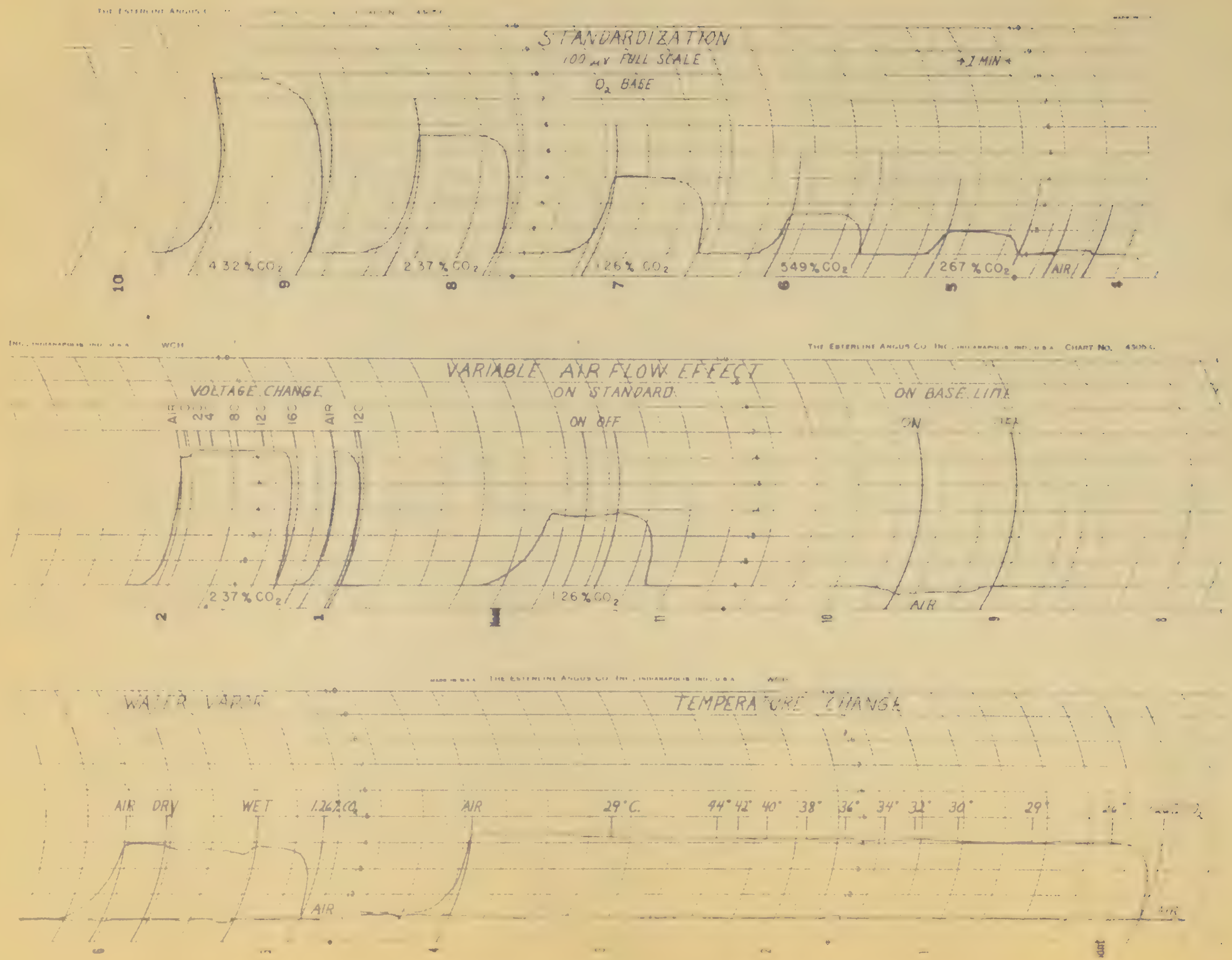


FIG. 2. STANDARDIZATION CURVES

TABLE 2

STANDARD CO_2 MIXTURES, MICROVOLT DEFLECTION

Per Cent CO_2	Average Microvolts	Maximum Microvolts
Oxygen (pure)	0.0 (by adjustment)	0.0 (by adjustment)
0.267	6.95	7.8
0.549	15.1	17.0
1.260	33.5	37.0
2.370	51.2	57.0
4.320	77.0	82.0

Average values were obtained by measuring the area under the curve for the entire period during which the test gas was running. This value, divided by the length of record, gave the average deflection for the period. Averages are lower than the maximum recorded deflections because of time lag in absorption and mixing. Ideally, both maximum and average values should have been identical; practically, the average value was of greater use for application to measurement of expired carbon dioxide.

b. Oxygen Versus Outside Air (0.03% CO_2).

Operation of the continuous gas analyzer over extended periods required repeated standardization of the base line because of electrical drift in the recording meter. This base line adjustment could have been made using cylinder oxygen, but in field work it was more convenient to standardize against outside air, a source material of constant carbon dioxide content more readily accessible than pure oxygen. A series of analyses was run, first to measure the sensitivity of the machine to the 0.03% CO_2 of air and second, to make direct comparison of standard mixtures using oxygen and air base lines. The average deflection produced by 0.03% CO_2 was slightly greater than 1 microvolt. The response is recorded in Figure 2. Comparison of the response of the machine to the known gas mixtures using the two base lines gave the conclusion that deflection response of the machine to carbon dioxide versus oxygen was slightly greater than response to the same carbon dioxide versus air. The effects were within the anticipated range for pure additive values, that is, 1-2 microvolt increase at each level. Curves comparing these responses are given later (Fig. 3).

c. Flow Change and Pressure Effects.

The apparatus was designed to give constant air flow to the analyzer but, to ascertain just what effects changes in rate of flow through the analyzer cell would have on the readings, a series of experiments was conducted. The effect of sudden complete cessation of flow and gradual decrease in flow were tested at the very low and at relatively high concentrations of carbon dioxide (0.03, 1.26 and 2.37%). Using the lowest concentration of gas (0.03% CO_2), the following results were obtained: sudden stoppage of flow caused a fall in deflection of 1 microvolt practically instantaneously; on return of the flow, there was a reestablishment of the original deflection within ½ minute; prolonged stoppage of flow (2 minutes) produced a decrease in deflection of 1 microvolt within ½ minute, then a

gradual fall of 1 microvolt over the succeeding $1\frac{1}{2}$ minutes; return of flow returned the deflection to its original level within $\frac{1}{2}$ minute. Similar effects although less marked, were seen with the higher concentrations of carbon dioxide: at levels of 1.26% CO_2, stoppage of flow caused a decrease in deflection of 2 microvolts within 1 minute; restoration of the previous level (29 microvolts in this case) required a little longer, 1 instead of $\frac{1}{2}$ minute. Gradual cessation of air flow was difficult to evaluate because with a constant speed motor variation from 12 to 10 liters per minute was the maximum obtainable (160 to 40 volts). Within this range no change in deflection toward 2.37% CO_2 could be shown. At a variac setting of 20 volts, the motor failed after a short period of 5 liters per minute flow. During this period, between 10 to 0 liters per minute flow, a fall of 3 microvolts occurred. The fall was probably identical with the effect of cessation of flow. All of the preceding data are illustrated in the second record of Figure 2.

d. Temperature Effects.

Previous work with the infra-red machine, when used for analysis of carbon monoxide, indicated that recordings were stable under gradual changes of temperature. Warning was implied to avoid sudden temperature change, although no commitment was made as to the magnitude of the error introduced (1). The influence of temperature change on carbon dioxide analysis has been investigated. Warm-up of the machine for $1\frac{1}{2}$ hours as recommended led to an analysis chamber temperature of 30°C. This temperature was maintained constantly while operating with ambient air of from 26° to 29°C. Preheating ingress air only slowly influenced the stabilized chamber temperature. Preheating inflowing air from 26° to 44°C. during a period of $\frac{1}{4}$ hour increased the analysis chamber temperature from 30° to 33°C. With the 3° rise in chamber temperature (exit air) the records showed a maximum upward deflection of 3-4 microvolts. The curve was flat between 30°-31°C with a 1 microvolt rise between 31°-31.5°C; a 2 microvolt rise between 31.5°-32°C; 3-4 microvolt rise between 32°-32.5°C; steady between 32.5°-33°C. Gradual increase in operating temperature caused positive deflection of the recorder pen for both outside air and 1.26% CO_2. This can be attributed to a shift in the base line. Sudden change of inflow gas from 44° to 29°C had no effect on the record. The only explanation of this fact is a lack of sensitivity of the instrument to sudden temperature change because the gas passing through the analyzer was not heated to chamber temperature. Esterline-Angus experimental records of these data are given in Figure 2.

e. Effect of Water Vapor.

The influence of water vapor upon carbon dioxide analysis was small, transitory and self-compensating. Air at 27°C saturated with water vapor caused an immediate downward displacement of the base line of approximately 2 microvolts. The effect was of 20 seconds duration, then the record reassumed its base line. With CO_2 mixtures, a similar but exaggerated downward shift occurred. Using a standard mixture containing 1.26% CO_2, saturation with water vapor caused a downward displacement of 3 microvolts which lasted 30 seconds at maximum, then decreased in effect until the original deflection was regained after 2 minutes. Dry gas replacing the moist which had reached balance caused no shift in deflection. The effects are probably not those of interference with flow because the time elapsed in

converting one mixture to another was very short. In addition, the immediate effects were greater than those produced by even prolonged flow stoppage. No flow change effect took place on converting from moist to dry gas. Records of these data are given in Figure 2.

f. Elapsed Time on Response.

Several factors have been reported as influencing the stability of the gas analyzer response to standard gas mixtures. The instrument has been regarded as satisfactorily stable if precautions have been taken to assure: (1) adequate warm-up, (2) well-charged batteries, (3) frequent zero adjustment of the established base line and (4) occasional standardization against a known gas mixture. The most likely factor to account for change in response has been stated to be an electrical leakage from terminals to ground. In those instances in which there has been a distinct loss of sensitivity with elapsed time the fault has been attributed to leakage of the filter cone (1). In the subject instrument leakage of gas had been minimized by a permanent cement seal of the analysis cell window to the filter cone assembly. Sensitivity control of the instrument had been incorporated so that one could adjust receptivity to a definite standard value. Duplication of standard curves by this means has been the practical way of controlling sensitivity loss (3).

During the accumulation of the following data, the sensitivity adjustment of the instrument was fixed in order to ascertain the absolute magnitude of inherent instrument sensitivity loss. Standardization curves taken at different times using both oxygen and air base have been run. Comparative curves for each series are given (Fig. 3). There was a loss of sensitivity during the 30 day period studied which was greater than casual variation between standardizations. There is insufficient evidence to attribute this loss to cone leakage on other than presumption from earlier reports. The practical method of adjustment of instrument sensitivity to a standard deflection with a known calibrating gas mixture nullifies the sensitivity loss.

g. Calibration of Curve.

The average deflection represented by each point in Figure 3 was arrived at by measurement, in square millimeters, of the area under each tracing during the test period. From this value, average deflection in millimeters was calculated. Each 10 microvolt deflection on the recording paper represented 11.5 millimeters. From these data the equation for standardization was obtained. All curves conformed roughly to the general equation:

$$C = K_1 \log K_2/K_2 - E$$

where C is CO_2 concentration in per cent, K_1 and K_2 are empirical constants and E is the microvolt deflection. Equation values for the curves of 19 March are tabulated (Table 3).

FIG. 3

STANDARDIZATION CURVES

TIME EFFECT

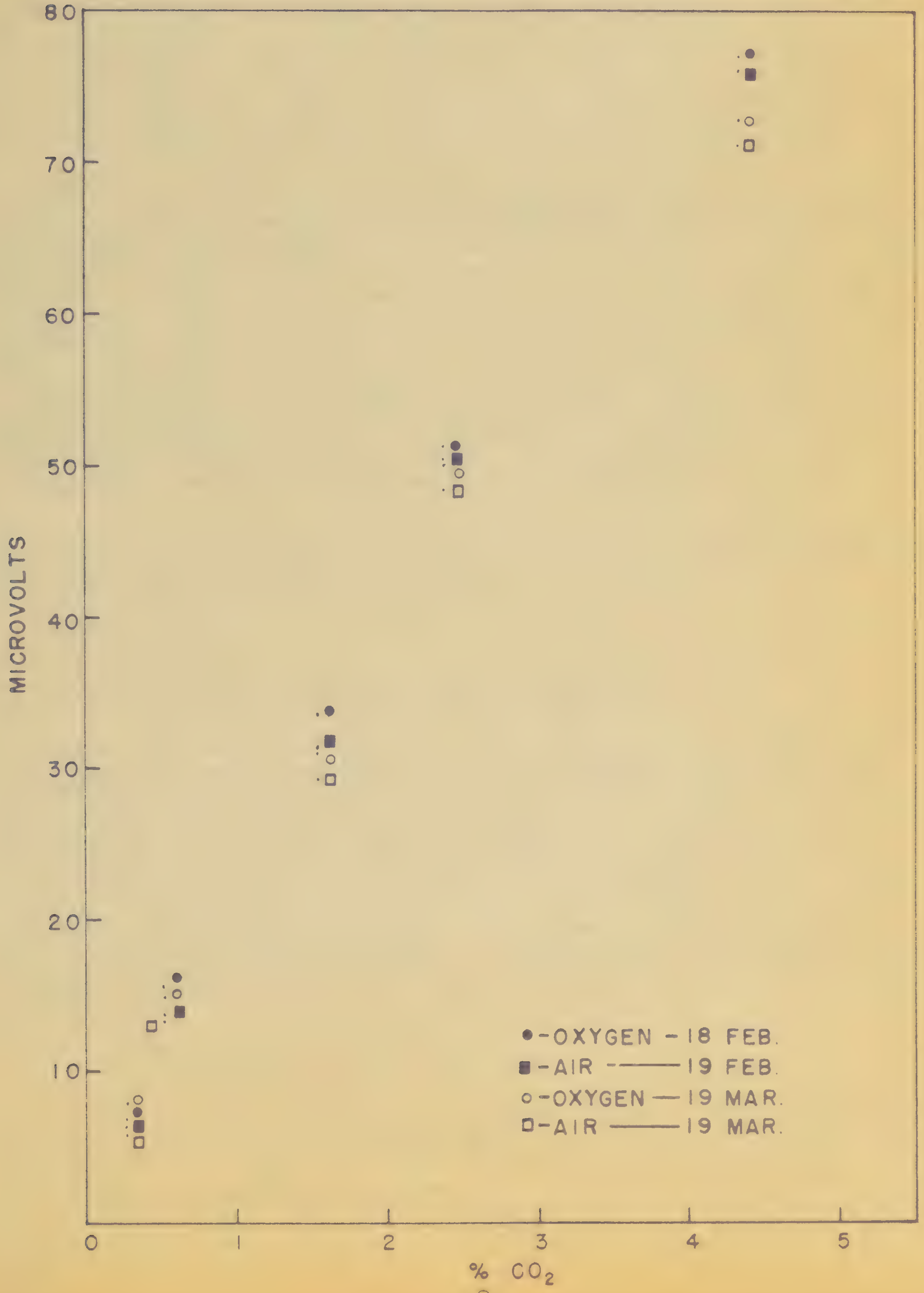


TABLE 3

CALIBRATION DATA FOR CURVES OF 19 MARCH

Conc. CO_2	Oxygen			Air		
%	μv	K_1	K_2	μv	K_1	K_2
0.267	7.70	7.90	103	5.76	11.2	107
0.549	14.7	8.21	103	13.7	9.21	107
1.26	31.1	8.08	103	29.3	9.08	107
2.37	50.0	8.04	103	48.4	9.07	107
4.32	72.8	8.10	103	71.2	9.08	107

In the above table, constant K_1 after establishment of K_2 should have been unchanged with variation of C and L within the individual series. The agreement was not perfect. Values at the higher concentrations of carbon dioxide, 1.26 through 4.32%, closely approached theoretical. The lower values were less predictable. Pure oxygen based values agreed more closely in the lower concentrations than did the air based values because the influence of the 0.03% CO_2 in air lowered deflection by decreasing the absolute concentration change of CO_2 presented to the instrument. Lack of completely theoretical response with oxygen base at low concentrations may have been due to either inaccuracy of record interpretation or slight errors in Haldane analysis rather than the apparent sensitivity variation of the analyzer.

In practice during subsequent work, the instrument has been standardized frequently and calibration curves have been run in conjunction with the metabolic experiments.

B. Results

1. Laboratory Tests on Human Subjects.

After calibration and standardization of the apparatus and recording instruments, application of the technique to measurement of energy expenditure was undertaken on 3 laboratory subjects. The subjects wore an A-13 oxygen demand mask, held in place by a "Juliet type" harness. This type of mask was chosen primarily because of its comfort and also for its adaptability to field conditions. To the mask was attached a hose leading to the analyzer assembly. Through mask and hose, air was drawn at a rate of 102 liters per minute. An analyzer aliquot was drawn by the pumping system previously described. The 3 subjects were used to adapt apparatus and technique to human energy study primarily with field application in mind.

a. Length of Main Line Hose.

The problem of the optimum length of hose which could be led from a subject without adversely influencing analytical accuracy was encountered. Initially 20 feet of hose from mask to instrument was tried. With this arrangement there was a definite variation of CO_2 content of the analyzed gases which corresponded with the subject's respiratory exchange. The volume through the analyzer was constant but, as had

been expected, air passing through the mask was richer in carbon dioxide during expiration than during inspiration. No attempts were made to synchronize these concentration changes with respiratory excursion during this study: first, because of inherent machine lag and second, because some line mixing made for distortion of the record. For ease of calculation and clarity of record a smooth curve was desired. This was obtained in two ways: (1) by use of a cyclonic type mixing chamber inserted in the analyzer flow line just ahead of the recording instrument, and (2) by use of a much longer (400 feet) lead hose from mask to machine. The latter method was adapted for field trials, the former for the laboratory work. Exercise curves obtained with 20 foot, 400 foot and 20 foot lead line with the mixer have been obtained. Each experiment was run on a different day and the time duration of each effort was adjusted by the subject to his ability rather than to a fixed schedule. There was no essential difference in average deflection produced by any type system. The variations seen are within the range of individual response to an exercise on repetition. A graphic interpretation of these data in terms of the average microvolt deflection during periods of rest, treadmill activity and recovery is given (Fig. 4).

b. Comparison of Energy Expenditure.

To compare energy expenditure between subjects, the CO_2 values obtained for each must be converted into caloric equivalent for a unit area of body surface over a definite period of time. Convention calls for expenditure per square meter body surface per hour or minute. Our subjects had been chosen as representative of the soldier group upon whom field studies were made. Their characteristics are tabulated (Table 4).

TABLE 4

PHYSICAL DATA OF LABORATORY SUBJECTS

Subject	Age	Weight	Height	Body Surface
R.P.	19	135	5' 10½"	1.77 M^2
W.H.	20	190	5' 8"	2.02
J.S.	19	158	5' 11"	1.90

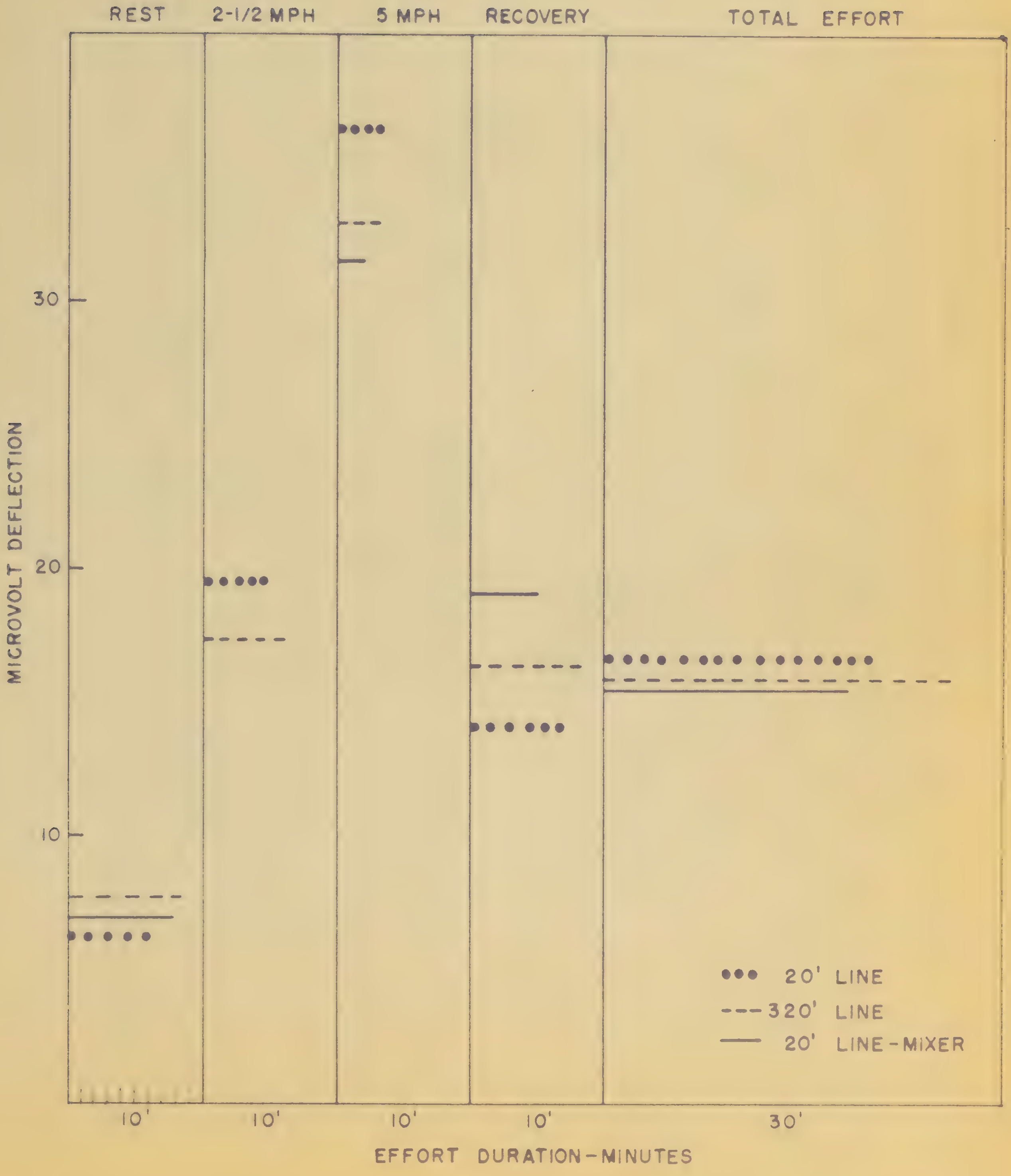
Using the laboratory technique of a 20 foot lead line and cyclonic air mixing chamber, a series of treadmill exercises was obtained on each subject. The severity and duration of each phase of the exercise were made strictly uniform between subjects. From these data the energy expenditure of the 3 men for each phase of the activity was compared.

A representative curve from 1 subject (W.H.) is given in Figure 5. Deflection in microvolts on the tracing represents CO_2 output during rest, level walking (2½ and 5 mph), a recovery period, additional rest, grade walking (10%, 2½ and 3½ mph) and recovery. The type curve was typical of all, although actual quantity output of carbon dioxide depended upon the individual. Equilibration of microvolt deflection to per cent carbon dioxide for any point on the curve was obtained from standard values. The air flow rate was maintained constant at 102 liters per minute. All air passing through the system came through the mask. All CO_2 recorded was that produced by the subject. An outside air base line was used and standardization against air had been accomplished. Deflection of the recording pen

FIG. 4

TREADMILL ACITIVTY

SUBJECT R.P.



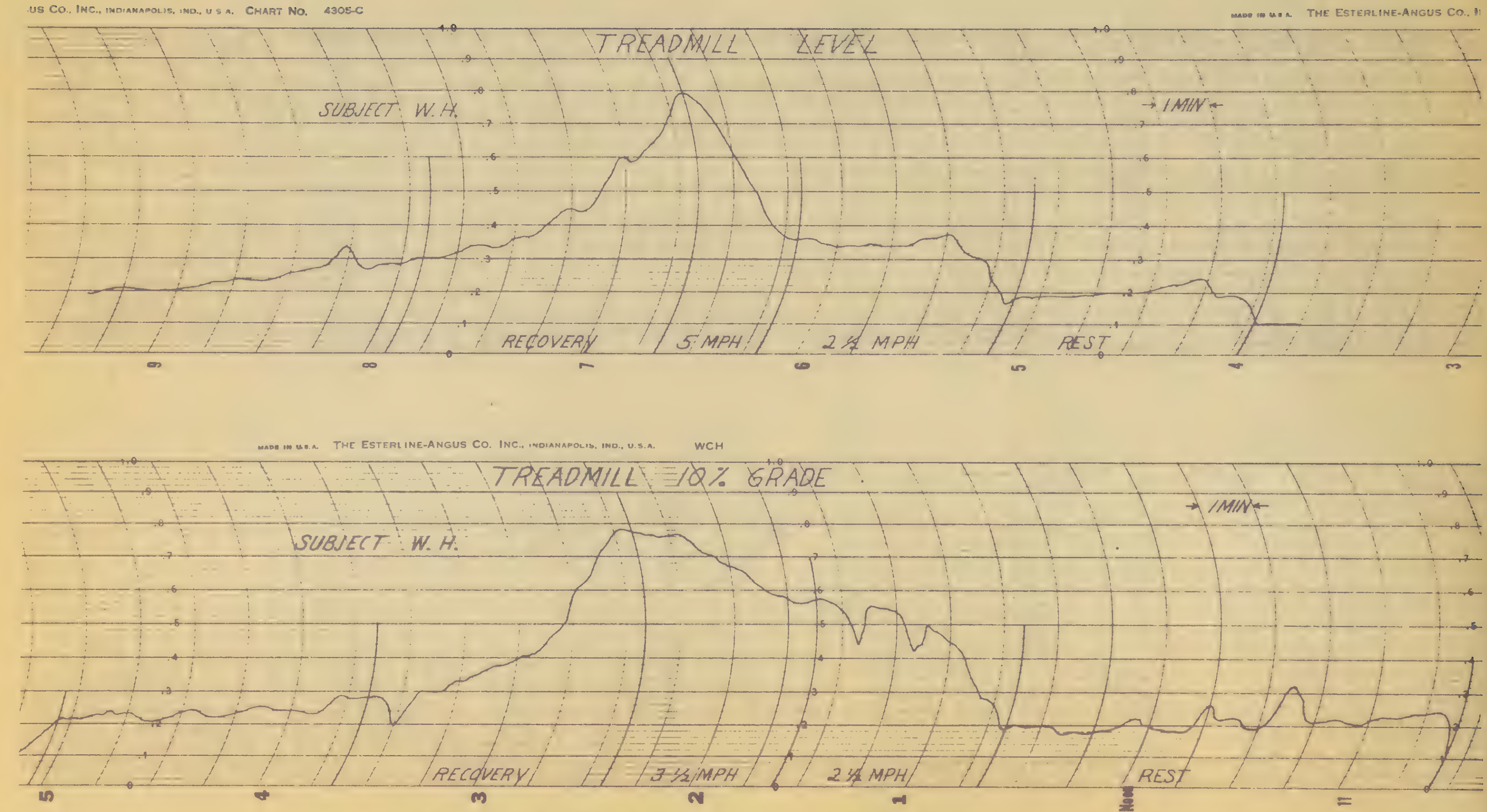


FIG. 5 ACTIVITY RECORD SUBJECT W. H.

directly measured CO_2 output. One gram of CO_2 is equivalent to 3 calories (5). By calculation, microvolt deflection could be read as calories per minute. To compare subjects, values must be made uniform by consideration of surface area. Figure 6 graphically compares the average caloric expenditure for each subject during each phase of the test exercise. The data are given as Calories per square meter body surface per minute. The value given in the figure as "rest" was evaluated by Haldane analysis in order to compare the infra-red method with a standard laboratory procedure. The comparison is given in Table 5.

TABLE 5

CALORIC EXPENDITURE AT REST, HALDANE AND INFRA-RED ANALYSIS

Subject	Calories/M^2/Hour		
	Haldane	Infra-Red	
R.P.	57.5	55.2	58.4
W.H.	58.5	60.2	61.2
J.S.	59.0	58.3	54.4

True basal rates for men of the age group are 45 Calories/M^2/Hour, therefore, the rest period should be considered pre-exercise.

2. Field Trials.

The Medical Department Field Research Laboratory was requested to determine the caloric expenditure of troops in mountain training during the test of operational rations at Camp Carson, Colorado, September 1946 (OQMG Ration Test #4631). Energy expenditure studies were made on representative soldier subjects undergoing prescribed mountain warfare training. The opportunity was taken to give the infra-red gas analyzer a full field trial. This trial included not only a comparison of the new technique with the standard field method of Douglas bag-Haldane analysis over terrain on which the latter could be applied (6), but also the the adaptation of the new technique to study of soldiers undergoing maneuvers the energy requirements of which had not been previously assessed. Technically, the studied climbs were: (1) mountain walk, a climb over a marked trail upon which both new and old analysis techniques were practiced; (2) scramble, a difficult climb over loose shale rock; (3) belay, free climb up a perpendicular rock face utilizing hand and foot holds; and (4) tension, or mechanically assisted climbing up an overhanging rock face. In addition to these data, direct comparisons have been made between different men undertaking identical activities, and also an assessment has been made of the influence of both confidence and experience on energy expenditure during mountain climbing training.

a. Adaptation of Gas Analyzer.

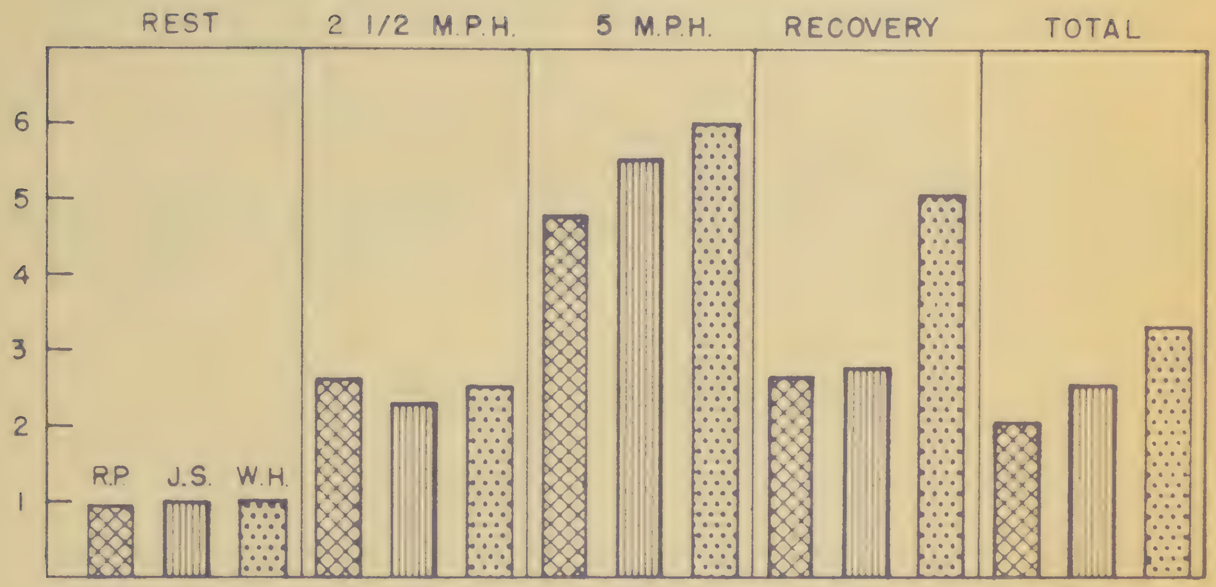
The selective gas analyzer and pumping equipment were mounted, for maneuverability, on a small trailer. The apparatus differed from the laboratory assembly in several respects: (1) a recording gas meter replaced the laboratory flow meter for registration of the rate of air flow, and (2) the machine had a different thermopile assembly from that used in the laboratory.

FIG. 6

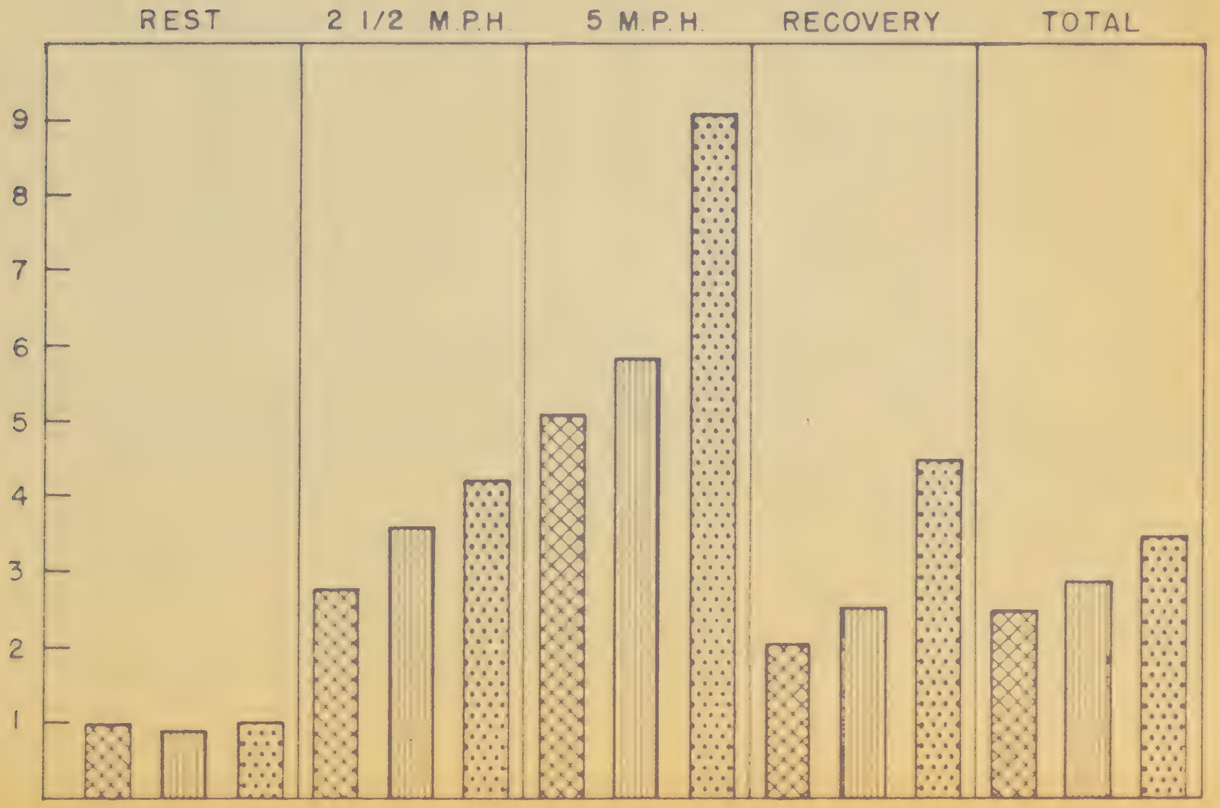
TREADMILL ACTIVITY

CAL / M^2 / MIN.

LEVEL



10 % GRADE



b. Lead Line Maneuverability.

A method for conveying the lead line hose which extended between the subject and recorder was developed on the basis of cable and pulley rigging. Taut cables were drawn between objectives on the particular rock-climbing terrain to be studied. Movable pulleys were mounted on the cables and from these pulleys was suspended the main line hose. A short lead of light hose connected the subject to the main line. Practically the entire weight of the hose assembly was supported mechanically, while the man on test was allowed maximum freedom. The trailer containing the analyzer and pumping apparatus was established at the cliff base. Four hundred feet of main line hose were arranged to reach each face to be studied.

c. Subjects.

Two subjects from each of 6 companies were used. The test companies were those of the ration study (Test of Operational Rations, Type E)(7). The subjects were approximately battalion average age, height and weight (Table 6).

TABLE 6

PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject	Height (inches)	Weight (pounds)	Age (years)	Surface Area (square meters)
H-063	71	141	18	1.66
H-025	68½	138	18	1.76
I-080	70	142	18	1.81
I-078	69	145	18	1.81
K-103	69	155	18	1.85
K-092	70½	148	19	1.84
L-032	70	194	19	2.08
L-110	70	170	19	1.96
M-114	68½	168	19	1.91
M-105	68	178	18	1.94
G-046	68	160	19	1.88
G-051	70	167	18	1.92

The metabolism study was coordinated with the battalion teaching schedule so that those men chosen were not deprived of their training. Each subject reported for energy expenditure studies according to a set schedule and was tested 3 times during the 1 month training period i.e., the 1st week, 2nd week and 3rd week. The severity of the assigned climb was governed by the subject's instruction in climbing technique. Early tests were simple mountain walking. Later tests were precision climbing, i.e., scramble, belay and tension. Some of the more difficult phases of the study were made only on those members of the group who were considered by their military training instructors to be proficient. This policy minimized accidents.

d. Analyses.

Two methods of analysis were used: the field adaptation of the classical Douglas bag-Haldane analysis technique, and the infra-red analyzer. The Haldane values for oxygen and carbon dioxide, with the metered respired volume obtained from the Douglas bag, were used to compute energy expenditure in terms of Calories per minute. The method of calculation for the infra-red analysis was identical with that used in the laboratory. Standard mixtures of carbon dioxide were used to establish calibration curves during the experimental period. The standardization curves for the analyzer conformed to the equation previously noted.

e. Comparison Between Haldane and Infra-red Analyses.

A relatively rugged mountain walk was chosen as a standard effort for the subjects in order to compare the caloric expenditure values obtained by both the Haldane and the infra-red techniques. This course consisted of a 200 foot uphill path, the average grade of which approximated 58 per cent. Douglas bag samples were taken at rest, during ascent, while recovering after ascent and during descent of the standard grade. Over the same course, at a different time, an infra-red analysis was made. The energy expenditure for each phase of the standard exertion for each subject is given in Table 7. Values obtained with the 2 methods were in closest agreement at resting levels. Increased exertion gave outputs which were comparable in trend and average only. The discrepancy between the 2 methods is best explained as due to individual variation in energy expenditure by a subject upon repetition of the same effort.

f. Comparison of Infra-red Analysis Curves Between Subjects.

The analysis curves for output of CO_2 demonstrated rather close contour agreement between subjects when taken as initial exposure to a particular type of exercise. In Figure 7 the analyzer curves, obtained from paired subjects undergoing 3 types of climbing training, are compared. They represent: (1) paired subjects undertaking quick time (120 steps per minute) and double time (180 steps per minute) marching; (2) climbing the 200 foot mountain walk previously described; and (3) ascent and descent of a 400 foot course of mountain walk and shale scramble. The curves have been superimposed. The elapsed times differ slightly. On both of the climbs between ascent and descent there was a five minute "break" or recovery period.

The 400 foot course was a continuation of the 200 foot standard grade, and consisted of an additional 200 feet of very difficult shale rock scramble. The grade was somewhat steeper than that of the previous effort. The carbon dioxide output, converted to Cals/M^2/min. for the total course showed fairly good agreement between men (Table 8).

TABLE 7

ENERGY EXPENDITURE CAL/M^2/MIN.

Subject	Area Sq. M.	Rest-before exercise		Ascent 200'		Recovery-post ascent		Descent 200'	
		Haldane	Infra-Red	Haldane	Infra-Red	Haldane	Infra-Red	Haldane	Infra-Red
L-032	2.08	.891	.802	4.86	5.21	1.27	2.58	2.20	3.78
L-110	1.96	.832	.796	4.26	4.35	2.12	2.61	2.39	3.28
H-025	1.76	.768	1.191	4.23	3.64	1.97	2.47	2.12	2.03
H-063	1.86	.661	.791	2.39	3.06	1.60	2.23	1.66	3.03
K-103	1.85	1.000	1.230	4.38	4.07	1.92	1.99	2.78	2.45
K-092	1.84	.952	.858	4.04	3.92	1.86	1.38	2.99	2.24
M-105	1.94	.944	1.000	4.35	2.94	1.53	2.48	3.12	2.37
M-114	1.91	.734	.644	3.48	4.02	1.29	2.04	1.94	2.65
S-046	1.88	.632	.665	4.89	4.33	1.70	1.98	2.49	2.59
S-051	1.92	.876	.906	3.74	3.34	1.37	2.08	2.73	2.43
I-078	1.81	1.022	.951	3.62	3.48	1.41	1.63	2.79	2.40
I-080	1.81	1.022	.813	4.86	2.94	1.82	1.60	2.84	2.36

FIG. 7

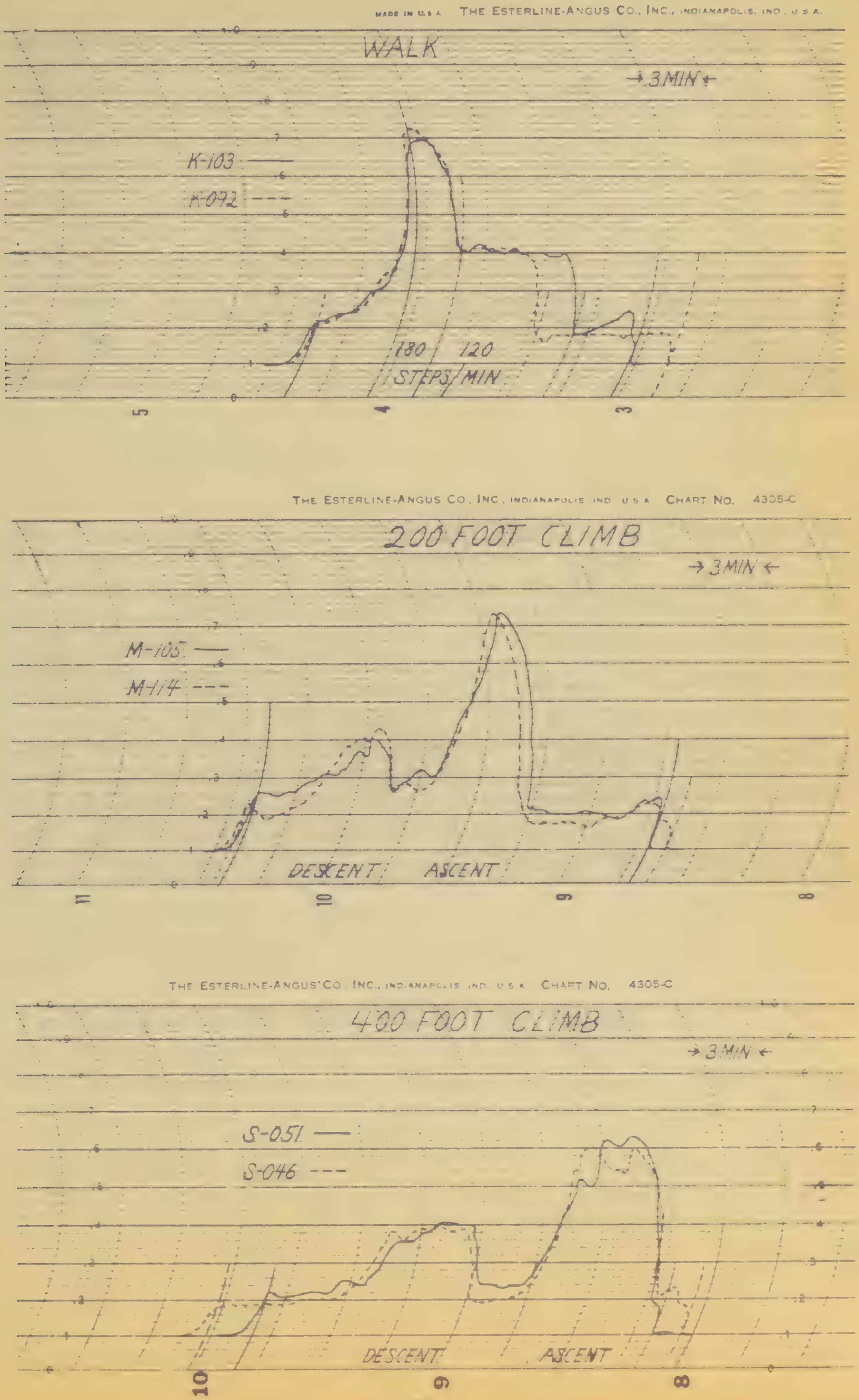

MADE IN U.S.A. THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A.
WALK
→3 MIN←
K-103 ——
K-092 - - -
180
120
STEPS/MIN
5
4
3
THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS IND. U.S.A. CHART NO. 4305-C
200 FOOT CLIMB
→3 MIN←
M-105 ——
M-114 - - -
DESCENT
ASCENT
11
10
9
8
THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS IND. U.S.A. CHART NO. 4305-C
400 FOOT CLIMB
→3 MIN←
S-051 ——
S-046 - - -
DESCENT
ASCENT
10
9
8

TABLE 8

FREE CLIMB AND SCRAMBLE - 400 FEET AND RETURN

Subject	Total Calories	Time min.	Cal./min.	Cal./min/M^2
L-032	90.1	16	5.64	2.71
L-110	111.2	20.2	5.54	2.82
H-025	108.7	23.3	4.66	2.65
H-063	99.1	21.8	4.54	2.44
K-103	92.4	25.4	3.63	1.96
K-092	111.5	31.0	3.59	1.95
M-105	87.5	22.3	3.93	2.02
M-114	87.4	22.9	3.82	2.00
S-046	82.1	23.2	3.54	1.88
S-051	84.4	22.7	3.72	1.93
I-078	107.7	24.8	4.34	2.40
I-080	77.8	19.5	3.99	2.20

g. Terrain Familiarity (confidence) in Belay Climb.

In the laboratory, repetition of the same exercise by a subject did not give identical energy distribution, for he was apparently able to govern his energy expenditure in accordance with anticipated need. In the field, familiarity with terrain gave the man added confidence which enabled him to perform an assignment in shorter time, at the same rate of caloric expenditure. In practice all comparisons have been made when the subjects had the same familiarity with a given terrain. Ideally, initial effort would have been preferable. To illustrate this point, we chose a difficult, totally unfamiliar climb and called for volunteers. Five of the 12 subjects agreed to undergo the test. Because of the hazard, the men were protected by a belaying line. This was a safety "check fall" rope from the man's body to an assistant above him in climb. No actual climbing aid was given by this rope, but its presence prevented serious falls. Each of the 5 volunteers made the climb (125 feet of perpendicular ascent) using only natural hand and foot holds. For all, it was avowed to be an initial attempt. Figures 8 and 9 picture the belay climb area with a subject and apparatus in ascent. Caloric expenditure and time requirements for the men are given in Table 9.

TABLE 9

BELAY CLIMB - CALORIC EXPENDITURE

Subject	Surface Area	Total Calories	Time min.	Cal/M^2/min.
K-103	1.85	106.1	21.0	2.72
K-092	1.84	74.6	14.6	2.74
H-029	1.80	101.5	19.0	3.14
H-025	1.76	84.0	15.0	3.18
I-080	1.81	104.5	17.3	3.36

FIG. 8. BELAY CLIMB AREA

FIG. 9. BELAY CLIMB

On the second attempt at the same belay climb, required time was cut by one third without proportionate rise in energy expenditure. This improvement was the result of confidence. The role of experience was checked on two men from outside of the test group. One of these was a mountain climbing instructor, and the other a presumably inexperienced "jeep" driver. Each volunteered to make the climb. The instructor attacked the climb immediately, made no false starts and completed the course in less than two thirds of the time required by the novice. The trained man's caloric expenditure was less than that of the untrained. In Figure 10 are records illustrating the influence of confidence and of experience.

h. Climbing Under Mental Tension.

The most difficult climb in mountain training was the "tension" climb, so named because the subject was under stress while climbing. There were no hand holds or foot holds; the climber ascended by driving steel pegs into clefts in the cliff face, and drew himself up from peg to peg by means of a sling rope. This climb was forbidden to the soldier subjects because of the danger, but the instructor who cooperated on the belay climb agreed to a demonstration. His energy expenditure was relatively low, and ascent very slow. During 10 feet of climbing which required 15 minutes, the caloric expenditure was 2.84 Cal/M^2/min.

i. Summary Values for Mountain Training.

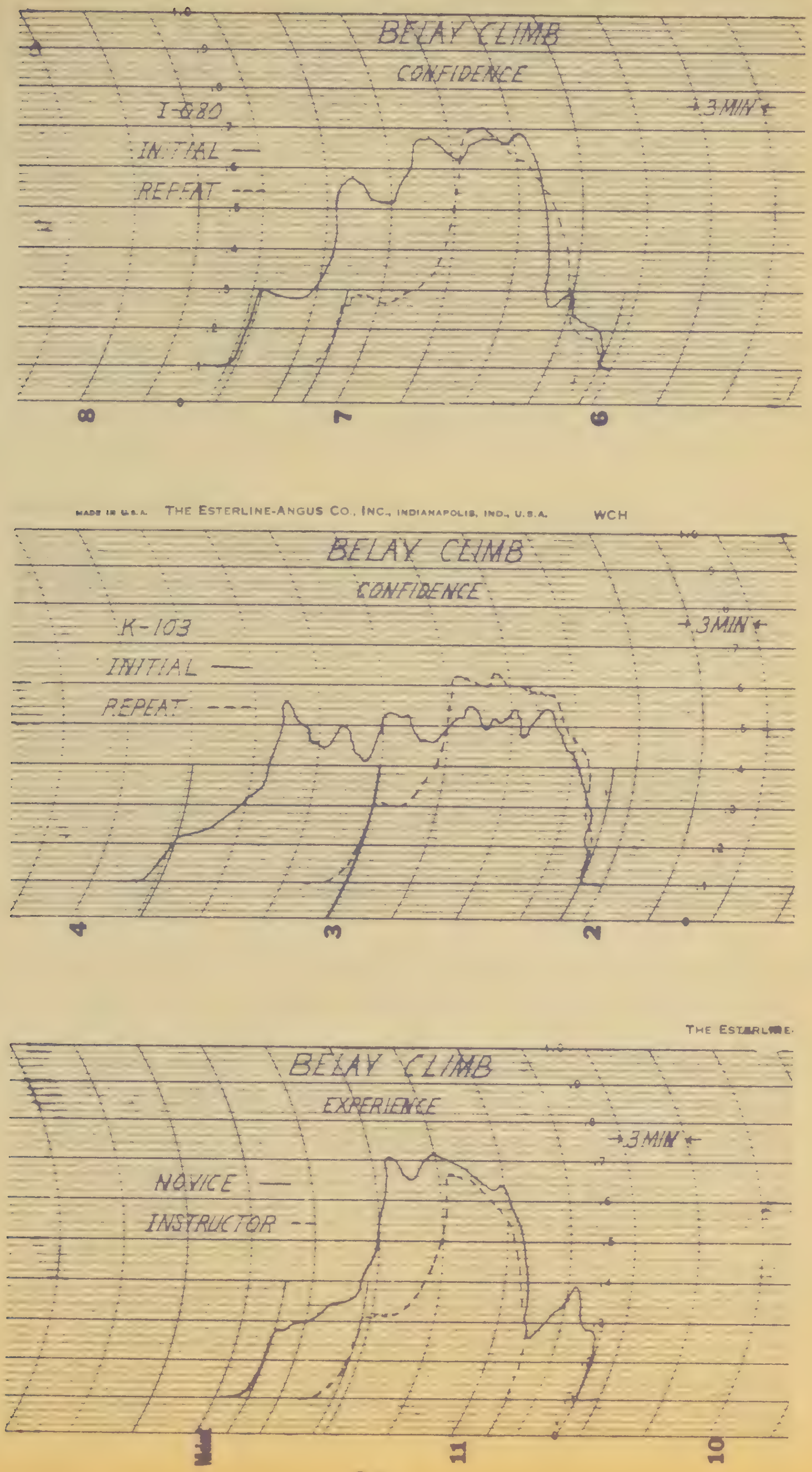
Summary values for energy expenditure of troops engaged in mountain training during the field trials are given in Table 10.

TABLE 10

MOUNTAIN TRAINING ENERGY EXPENDITURE (AVERAGES)

Activity	Cal/M^2/Minute
Rest (before exertion)	0.89
Quick Time March (120 steps/min.)	2.59
Double Time March (180 steps/min.)	5.04
Free Climb and Mountain Walk (200' course & return)	2.04
Ascent	3.77
Descent	2.09
Recovery (break period)	2.55
Free Climb and Scramble (400' course and return)	2.25
Belay Climb	3.03

FIG. 10


BELAY CLIMB
CONFIDENCE
I-680
INITIAL —
REPEAT ---
3 MIN
8
7
6
MADE IN U.S.A. THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A. WCH
BELAY CLIMB
CONFIDENCE
K-103
INITIAL —
REPEAT ---
3MIN
4
3
2
THE ESTERLINE
BELAY CLIMB
EXPERIENCE
NOVICE —
INSTRUCTOR --
3 MIN
11
10

III. DISCUSSION

A new technique for measurement of caloric expenditure during continuous activity has been developed. Both laboratory and field trials have proved the adaptability of the Leeds and Northrup selective gas analyzer to the estimation of carbon dioxide in expired air. Caloric expenditure studies on men undergoing mountain warfare training have been accomplished. The new method offers instantaneous analysis and continuous records over protracted periods of exercise. These criteria have not been met by previous methods.

IV. CONCLUSIONS

The Leeds and Northrup infra-red gas analyzer sensitized for carbon dioxide detection and equipped with an adequate pumping system for controlled air flow has been adapted to metabolic work and found satisfactory both in the laboratory and in the field. The A-13 oxygen demand mask in conjunction with long air lines carried by cable and pulley rigging offered a light weight, comfortable, non-restraining respirator for field study of energy expenditure. Energy output studies on representative soldier subjects engaged in mountain warfare training have been recorded.

V. RECOMMENDATIONS

The apparatus developed and tested is satisfactory for routine study of respiratory exchange. To obtain absolute fidelity, i.e. synchronization of recorded response with respiratory excursions, and continuous analytical records of oxygen utilization, should be the aim of subsequent investigation.

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OBSERVATIONS ON THE RELATION OF HEIGHT OF HEEL AND SUPPORT IN ARCH OF SHOES TO FOOT PHYSIOLOGY IN MARCHING TROOPS[1]

by

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from

Medical Department Field Research Laboratory
Fort Knox, Kentucky, 16 September 1947

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[1] Sub-project under Survey of Foot Measurements and Proper Fit of Army Shoes (MDFRL- 53). Approved by CG, ASF, 11 September 1945.

m.P

Project No. 51-1 16 September 1947
[illegible]

ABSTRACT

OBSERVATIONS ON THE RELATION OF HEIGHT OF HEEL AND SUPPORT IN ARCH OF SHOES TO FOOT PHYSIOLOGY IN MARCHING TROOPS

OBJECT

To determine the value to foot health of support in the arch and heel of the feet of marching troops. The control shoes, army service shoe, Type III, and combat boots were compared with experimental shoes with a low heel and with those in which the steel shank support in the longitudinal arch had been removed.

PROCEDURE

Recruits were selected at random on a voluntary basis and observations made during a conditioning period and an experimental period. During both periods the troops were divided into a control and an experimental group and marched up to 13.5 miles a day at 3.2 miles per hour for 5 days each week. For the shankless shoe experiment, the troops wore their own "broken in" army service shoes, Type III, during the conditioning period; during the experimental period half the feet were equipped with standard service shoes, Type III, the other half with the experimental shankless shoe. For the low heel experiment, troops wore their own "broken in" combat boots during the conditioning period; during the experimental period half the feet were equipped with combat boots, the rest with the low heel experimental shoes. Foot lesions were determined twice daily.

RESULTS AND CONCLUSIONS

There was no essential difference between the effect of the control and experimental shoes on the foot health of marching troops as evidenced by the frequency, type, duration, distribution, time of onset, and severity (march time lost due to lesions) of the clinical lesions present.

In the shankless shoe experiment, the superficial lesions constituted 79 per cent of all lesions, the deep lesions 21 per cent; in the low heel experiment, superficial lesions made up 57 per cent of all lesions. The most common lesions were blisters, erythemata, calluses and deep pain. Most lesions were located in the toe, metatarsal, and heel regions.

After the march period, both worn standard service and experimental shankless shoes were somewhat lower in the arch region, with the shankless shoe about 3 per cent lower. The shankless shoe had a considerably greater upward curvature of heel and toe, and a more flexible sole with manual manipulation. This factor gave the shankless shoe a less favorable appearance and possibly had a deleterious effect on the durability of the shoes.

Whether more critical tests will reveal dynamic or static changes in bones and their relationship at the same or greater marching distances remains to be determined.

RECOMMENDATIONS

That further studies in support of the foot by shoes be carried out, testing the other regions of support and their possible combinations.

That these investigations should also include studies of the dynamic foot-shoe relationship using motion picture X-rays.

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OBSERVATIONS ON THE RELATION OF HEIGHT OF HEEL AND SUPPORT IN ARCH OF SHOES TO FOOT PHYSIOLOGY IN MARCHING TROOPS

I. INTRODUCTION

Inhabitants of many countries wear some form of foot apparel for supportive and/or protective purposes. However, whether any of the multiple types of footgear favors foot health as compared with a "bare-foot-to-ground" relationship has not been determined.

Different types of shoes vary greatly in the degree of support* given to the foot. In the army standard service shoe for marching and walking purposes (fig. 1), support is usually attained by (1) a heel which raises the posterior part of the foot above the forepart, (2) a shank (leather and/or metal) which elevates the longitudinal arch, (3) a stiff counter which supports the sides of the heel, (4) an upward curvature of the sides of the insole, (5) constriction or "girdling effect" of the lateral and medial aspects of the foot, and (6) sole rigidity.

In World War II, using a shoe of this design, contributions from various agencies indicated that only a small percentage of our soldiers was properly fitted with footgear (7), and it was estimated that possibly 20 per cent of all dispensary visits in the Army were due to foot troubles, many of which were traceable to improperly fitted footgear. Although considerable investigation has concerned itself with the anatomy, physiology, and functional disorders of the feet (1 through 28), little or no specific information is available to determine whether the regional types of support (separately or in combination) indicated above are beneficial to the state of health of the feet of marching troops. Therefore, investigations were undertaken to test the role of support in foot health. The studies were restricted to consideration of the physiological effect of the removal of the shank and of a decrease in heel height of the shoe. These factors were tested by determining their effect on the frequency, type, duration, distribution, and time of onset of clinical foot lesions and on the ability of troops to march.


Figure 1
REGIONS OF SUPPORT
IN
ARMY SERVICE SHOE

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*The term, "support," is here used to indicate any construction characteristic of a shoe which alters the "bare-foot-to-ground" relationship.

II. METHODS AND PROCEDURES

Although the observations on the subjects wearing shankless shoes* and low-heel shoes* were made at different times and on different groups of troops, the methods and procedures were largely similar for both and will be considered together.

Recruits were selected at random on a voluntary basis from Replacement Training Center at Fort Knox, Kentucky, and a medical history and physical examination taken. There were no significant physical disabilities and no past history of disease, injury, or abnormality which might lead to foot troubles. Special note was made of the extent of previous marching or walking, foot complaints and injuries, the clinical foot type (27), presence of fungus infections, and other lesions. All lesions were treated to keep the subjects on the march. Fungus infections were treated with salicylic acid until arrested or cured. Blisters, abrasions, and painful corns were treated with moleskin adhesive plasters, and occasionally blisters were punctured.

Observations were made during a conditioning period and an experimental period. During the conditioning period the subjects were divided into a control and an experimental group and all subjects marched 5 days a week. The daily mileage was gradually increased from 5 to 13.5 miles by 4-day intervals and maintained at the latter distance for the rest of the period. The rate of march was about 3.2 miles per hour (116 thirty-inch steps per minute) with 10-minute rest periods every 50 minutes, and an hour for chow in the field at noon. Foot inspections were made twice daily, immediately preceding the day's march and following a shower and change of shoes at the end of the day's work. Occasional, unannounced inspections were made 5 minutes before or during a march. For each inspection the men were divided alphabetically into three groups which were rotated through three examining medical officers. Careful check was made on foot lesions arising from non-march activities during the evenings and over the week-ends.

The route of march, 13.5 miles in length, was carefully laid as to type of terrain, distance, avoidance of traffic, and facilities for messing in the field. To insure that the men marched under all-weather conditions, three alternate routes were laid out including equal distances of cross-country, hard dirt and gravel, and concrete; all over rolling terrain. The concrete surface was used only twice in each experiment.

For the shankless shoe experiment during the conditioning period, the shoes worn by the troops were their own "broken in" service shoes, Type III, with reversed uppers and composition soles. During this experimental period standard service shoes were worn on both feet by group 1; on the left foot by group 3; on the right foot by group 4;

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*Constructed by the Selby Shoe Company, Salem, Massachusetts, under direction of F. M. Gill, Office of the Quartermaster General.

shankless shoes were worn on both feet by group 2; on the right foot by group 3; and on the left foot by group 4.

To test the effect of low-heel shoes the troops wore their own "broken-in" combat boots during the conditioning period. During the experimental period the new experimental shoe was worn in which the heel height had been lowered by 1/4 inch. To do this it was necessary to construct a special shoe last which corrected for the reduced height of the heel.

In case of shoe misfit (28), at the initial examination before the conditioning period, other acceptable "broken in" standard service shoes or combat boots were substituted. The subjects were told that all shoes worn during the experimental period were identical. In addition to shoes, troops wore cushion sole socks (OD 73531824); HBT trousers, jacket and cap; cotton drawers and undershirt; pistol belt and canteen; but no leggings or pack. Socks were changed and foot powder (No. 12040) used before each day's march. The marching regime, foot inspection, shoe fittings, and supervision were identical in both experiments and in all periods.

The state of foot health was estimated by observing the anatomical location, frequency, and clinical types of foot lesions together with the march time lost because of these lesions. The lesions were recorded as (1) subjective (those felt by subject in his feet), (2) objective (those detected by the examination through observation, palpation, or percussion), (3) superficial (those believed confined to the moveable fleshy parts of the foot, i.e., skin, superficial fascia and fat), and (4) deep (those apparently in the muscles, tendons, ligaments, fascia, periosteum, bones and joints). The differentiation into deep and superficial was determined by the physical findings and/or subjective reactions. The superficial lesions included blisters, calluses, corns, abrasions, erythemata, contusions, ingrown nails, and plantar warts. The deep lesions included deep pains*, sprains, and tenosynovitides. The types of foot lesions found were limited to these eleven.

The location of the lesions in the foot and leg (see fig. 2) was arbitrarily divided into 7 convenient anatomical regions: (1) toe, including phalanges and all overlying tissue, (2) metatarsal, including metatarsals and all overlying tissue, (3) tarsal, including tarsals and all overlying tissue but not the calcaneus and talus, (4) heel, including calcaneus and all overlying soft tissue, (5) ankle, including ankle articulation, medial and lateral malleoli and their ligaments, the talus and all overlying tissue, (6) lower leg, including tibia, fibula, and

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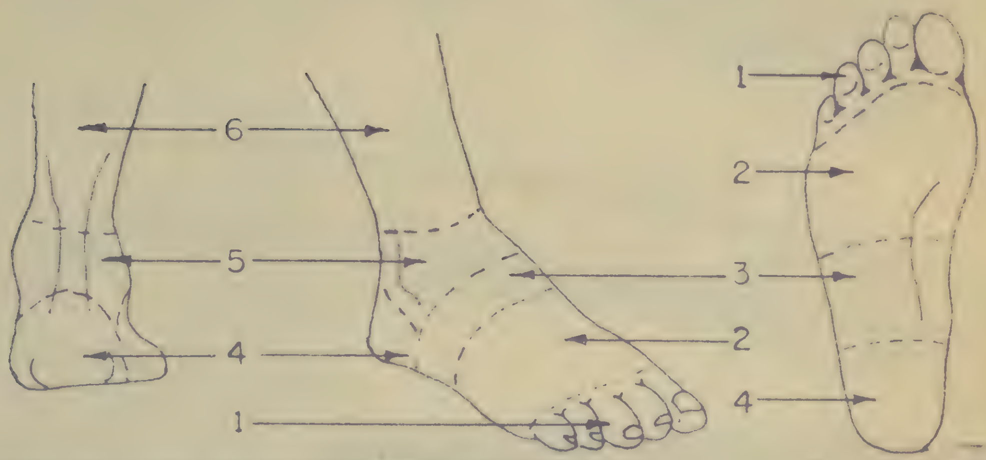
*The term, "deep pain," or "ache," as the investigators use it, refers to an aggregate of lesions consisting of metatarsalgia, digitalgia, talalgia, Morton's syndrome, hypermobility of first metatarsal bone, painful heel (exostoses, osteitis, apophysitis, bursitis, fascitis), hallux rigidus, march fracture, metatarsal arch depression, and prominent scaphoid.

all overlying tissue, (7) knee, including knee articulation, ligaments and all overlying tissue. All instances of joint space involvement were listed as being located in the next proximal region.

FIG. 2

ANATOMICAL REGIONS



At the end of the experiment in which shankless shoes were used, foot-in-shoe X-rays were taken to determine the relative amount of sag of the foot and shoe in the arch region. To do this, two lines were drawn with 35 per cent barium sulfate in collodion: (1) a <u>skin line</u> along the median plane of the plantar aspect of the foot extending from the heel to the region underlying the head of the third metatarsal, (2) a <u>shoe line</u> following the mid-line of the shoe's inner sole (fig. 3). These two lines, separated only by a cushion sole sock, overlay each other. Measurements (using dividers and an accurate metric scale) were taken of the distance of these lines above the base or ground line. The most posterior point was the notch formed by the front edge of the heel insole. The other three points were selected at 1 cm. intervals in front of this.

X-ray measurements were not considered necessary in the experiment in which low-heel shoes were tested because the difference in heel height was easily demonstrated and measured.

All cases which exhibited symptoms or findings which might have been attributed to march fractures were thoroughly studied, making use of repeated X-rays as well as daily physical examinations. No march fractures were encountered in either experiment.

Throughout the experiments strict military discipline was maintained over the subjects. Except during actual marches neither experimental nor control shoes were worn; low quarter shoes with cotton socks were worn off march. Passes were granted from Friday evening to Sunday evening. A standard army diet of 3500 calories per day was provided; water and salt were taken <u>ad lib</u>. Smoking was permitted at all times except when marching at attention (on concrete roads). A medical officer accompanied each march to insure strict compliance with the condi-

tions of the experiment and to make such medical observations as the experiment required.

FIG. 3 SAMPLE X RAY STUDY
STANDARD SERVICE SHOE

III. RESULTS

A. Shankless Shoes.

The physical data on the troops and the weather encountered are contained in Table I and fig. 4. The conditioning period lasted 24 days, the experimental period 34 days. There were 41 feet in the control group, 37 in the experimental group.

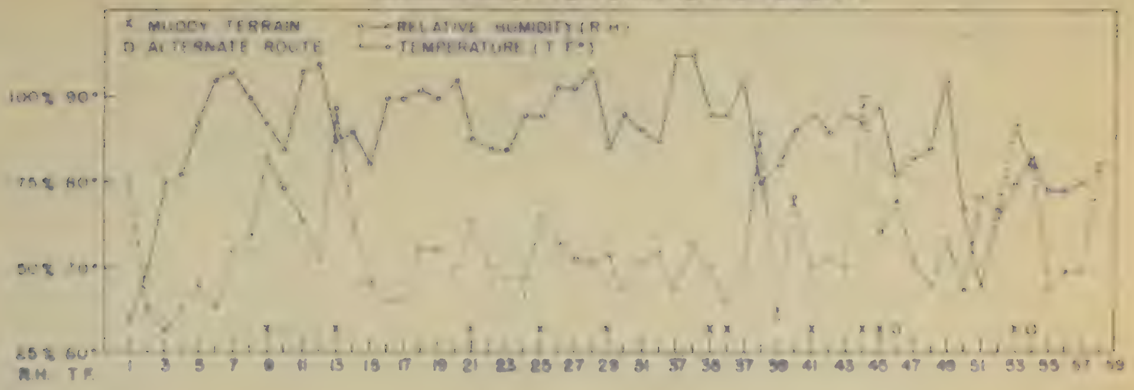
Table 1

Age, Height, and Weight Data

Group	Age (yrs.)		Height (cm.)		Weight (kilo.)	
	Range	Average	Range	Average	Range	Average
1	18-22	18.9	163.7-186.7	175.4	58.4-81.7	68.3
2	18-19	18.1	166.8-177.8	173.1	57.4-82.3	67.6
3	18-19	18.3	161.2-185.2	175.9	57.9-76.2	67.3
4	18-19	18.3	169.1-185.3	176.2	58.5-79.1	65.5
Average	18-22	18.4	161.2-186.7	174.9	57.4-82.3	67.3

FIG. 4

MAXIMUM DAILY TEMPERATURE AND HUMIDITY



1. Initial and final foot inspections. The incidence of the various clinical types of feet is indicated in Table 2. The majority fall in the "normal" group. There were no cases of eversion, inversion, or low arch in either group; i.e., foot types which might need correctional shoes. Initially, clinical and laboratory examination showed epidermophytosis to be present in 87 per cent of the subjects. The initial and final clinical foot inspections revealed relatively few lesions, with blisters, calluses and corns predominant in both groups. Initially, the number of lesions in the control and experimental group was 16 versus 11; finally, 30 versus 28. (For further details see Appendix 1.)

Table 2

Clinical Types of Feet

Type	Control Group	Experimental Group
"Normal"	13	14
Asymmetrical Heel	4	4
Long Toes	2	3
High Arch	-	2
Lean Foot	-	1
Fleshy Foot	-	1

2. New Lesions. Comparison of the two groups in the conditioning and experimental periods is contained in Table 3. In the experimental period as compared to the conditioning period, the new lesions increased in both groups. However, on the basis of new lesions per day and per foot, the relationship of the values for the troops wearing ankleless shoes (experimental group) to those for the control group did not differ significantly, either in the individual periods or in the average for both periods. (Further details are in Appendix 1.)

Table 3

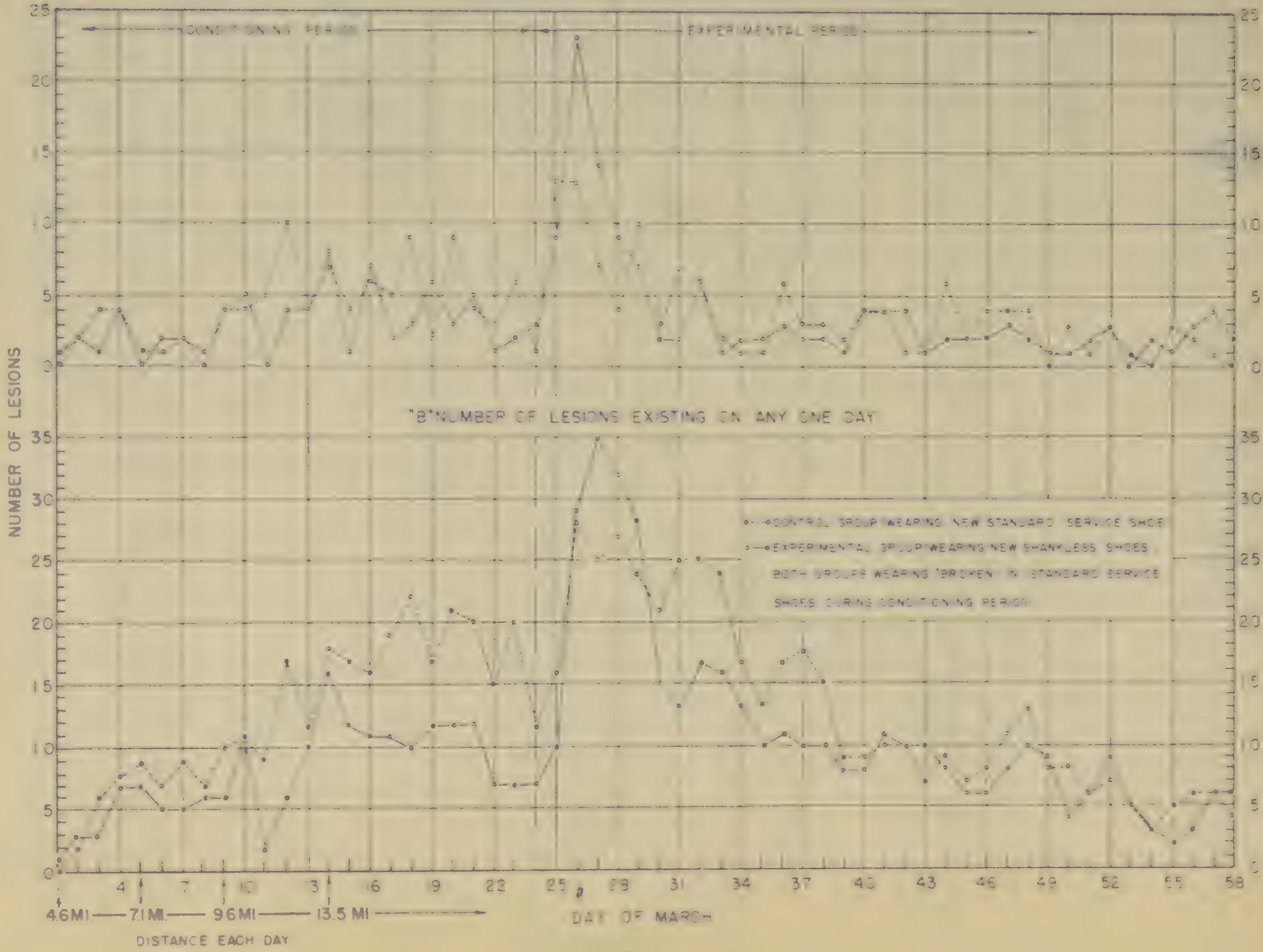
Basic Data

	Conditioning Period		Experimental Period		Both Periods	
	C	E	C	E	C	E
Feet	41	37	41	37	82	74
Days	24	24	34	34	58	58
March Days of Lesions	304	189	446	387	[illegible]	576
Week-end Days of Lesions	99	67	113	[illegible]	[illegible]	166
Total Lesion Days	403	[illegible]	559	[illegible]	[illegible]	[illegible]
New Lesions	97	79	125	142	222	221
Per Day*	4	[illegible]	3.7	[illegible]	3.4	[illegible]
Per Foot	2.3	[illegible]	3.0	[illegible]	2.7	2.9
Av. Duration Days**	4.1	3.5	4.4	[illegible]	[illegible]	3.7
Av. Duration Days Per Foot***	7.6	[illegible]	[illegible]	10.4	[illegible]	[illegible]
Total Lesions	304	198	[illegible]	389	740	[illegible]
Per Day*	12.7	[illegible]	13.7	[illegible]	[illegible]	[illegible]
Type, Superficial	77	55	105	110	[illegible]	[illegible]
Blister	53	41	72	79	125	[illegible]
Erythema	10	3.3	21	[illegible]	31	21
Callus	6	2.2	5	7.8	11	10
Corn	3	3.3	2	1	5	[illegible]
Rest	5	5.5	5	[illegible]	10	[illegible]
Type, Deep	20	23.3	20	32	40	[illegible]
Pain	18	25.3	19	32	37	[illegible]
Rest	2	0	1	0	3	[illegible]
Type						
Objective	21	16.4	31	12.2		
Subjective	9	10	2	7.8		
Objective and Subjective	67	52	112	122		
Location						
Toe	44	25.5	54	53	98	79
Metatarsal	34	34.3	50	[illegible]	84	82
Heel	8	8.9	14	21.6	22	39.5
Rest	11	10	7	14.4	18	24.4

*Calculated in proportion to number of feet in group.
**Based on total lesion days.
***March lesion days divided by feet in group.

Fig. 5A compares the incidence of new lesions from day to day for both groups and periods. There is no essential difference between the experimental and control group curves in either period as to pattern or frequency of lesions. No correlation exists between the times of increase in mileage and the incidence of lesions. During the conditioning period, as the length of march increases from 4.8 to 13.5 miles per day, the number of new lesions per day increases mildly from 0 and 1 in each group on the first day to maximum values of 10 and 8 during the last half of the period, but the final values for each group

FIG 5



"A" NUMBER OF NEW LESIONS EACH DAY

"B" NUMBER OF LESIONS EXISTING ON ANY ONE DAY

approximate those of the first day. During the experimental period and with a constant mileage per day, the new lesions in each group increase to new high levels with the curve for the experimental group temporarily somewhat higher, but after the fourth experimental day (29th day), the values are well within the range of those obtained during the conditioning period where they remain for the rest of the experimental period. Forty-three per cent of all lesions starting in this 34-day period appeared within the first 5 days.

3. Total Lesions*. Comparison (Table 3) shows that the total lesions and lesions per day in the control group were greater in both periods. However, during the experimental period, the wearing of the shankless shoe increased the number of lesions more than did the use of the new standard service shoe so that the ratio (control/experimental) in this period and the average for both periods decreased mildly as compared to that existing in the conditioning period. (See Appendix 1.)

The curves for the control and experimental groups approximate the same height (except during the last half of the conditioning period), and follow the same general pattern during both periods (Fig. 5 B). Again, there is no correspondence between the changing mileage per day and the number of lesions per day. During the conditioning period the total lesions increase to maximum levels of 10 to 20 at about the 14th day, at which level they are roughly maintained with the group wearing standard service shoes being maintained at the higher level. During the experimental period the lesions in both groups increase to reach a maximum of 25 to 30 per day during the first 5 days, and thereafter fall progressively to values of 5 to 10, approximating the values existing during the early part of the conditioning period.

4. Clinical Types of Lesions. The data on the more frequently occurring types are summarized in Table 4. Superficial lesions predominated in each group during both periods, averaging 79 per cent of all lesions. Blisters and erythema made up 86 per cent (71 and 15, respectively) of all superficial lesions.

Deep lesions made up 21 per cent of all lesions. Of these, pain predominated in both groups and periods constituting 97 per cent of the deep lesions.

In the two periods, considered separately or averaged together, the incidence of the more commonly occurring superficial or deep lesions compared favorably in the control versus the experimental group. (See Appendix 1 for details.)

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*These data include all lesions regardless of whether they started in the conditioning or experimental periods.

In both groups most of the lesions were a combination of subjective and objective types, and in each period the ratios for the 2 groups were comparable (Table 4).

Table 4

Clinical Nature of Lesions

A. Percentages of Superficial and Deep Lesions

	Conditioning Period				Experimental Period				Both Periods			
	Superficial or Deep Lesions		Total Lesions		Superficial or Deep Lesions		Total Lesions		Superficial or Deep Lesions		Total Lesions	
	C	E	C	E	C	E	C	E	C	E	C	E
Type												
Superficial			79	70			84	77			82	75
Blister	69	74	55	52	68	72	57	55	69	73	56	55
Erythema	13	6	10	4	20	16	17	13	17	13	14	10
Callus	8	4	6	3	5	7	4	5	6	5	5	4
Corn	4	6	3	4	2	1	2	1	3	3	2	3
Rest	6	10	5	7	5	4	4	3	5	6	5	4
Deep			21	30			16	23			18	25
Pain	90	100	19	30	95	100	15	23	92	100	17	25
Rest	10	0	2	0	5	0	1	0	8	0	1	0

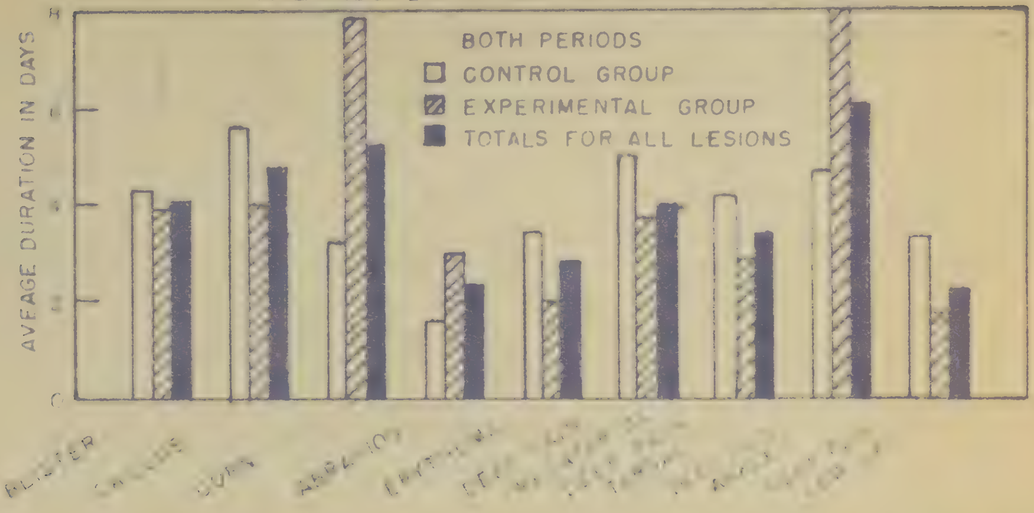
B. Percentages of Objective and Subjective Lesions

	Conditioning Period		Experimental Period		
	C	E	C	E	
Type					
Objective	22	21	9	9	
Subjective	9	13	2	6	
Obj. & Subj.	69	66	89	85	

5. Duration of Lesions. The considerable increase during marching of the total number of lesions existing each day is related to the data in Table 3 and fig. 5, showing that the duration of the various lesions was considerable and varied from 2 to 8 days, with the average approximating 4 days. The average duration of lesions in days and the average lesion days per foot increased in both groups during the experimental period, but the ratios of these values were roughly similar in both the conditioning and experimental period. Although, as already indicated, the frequency of the superficial lesions was approximately four times that of the deep lesions, the duration of the deep lesions was in the range of that of the superficial lesions for both periods. Again, for both superficial and deep lesions, there was no essential difference between the values averaged for both periods for the control versus the experimental group.

Fig. 6

AVERAGE DURATION OF COMMON LESIONS



6. Anatomical Location of Lesions. Table 5 gives the distribution of lesions by region and type. Three regions, toe (40%), metatarsal (38%), and heel (13%) contained 91 per cent of all lesions with very little difference in the figures for the different periods and groups considered separately or together. Superficial lesions predominated in all regions; the deep lesions were almost entirely restricted to the metatarsal region. In the toe and heel, 99 and 95 per cent of the lesions were superficial. In the metatarsal region, 72 per cent were superficial; of the deep lesions, 98 per cent were pain. In the above three regions, blisters and erythema made up 87 to 88 per cent of the superficial lesions. (See Appendix 1 for details.)

Table 5

Location of Lesions

	Conditioning Period				Experimental Period				Both Periods			
	Superficial Lesions--%		All Lesions--%		Superficial Lesions--%		All Lesions--%		Superficial Lesions--%		All Lesions--%	
	C	E	C	E	C	E	C	E	C	E	C	E
Toe	100	100	46	32	98	100	43	38	99	100	44	36
Metatarsal	70	58	34	44	72	58	40	34	72	60	38	37
Heel	100	100	8	11	93	92	11	18	95	94	10	15
Rest	5	11	11	13	43	32	6	10	22	23	8	11

7. Time of Appearance of Lesions. Table 6 illustrates the chronological period of the march in which the 3 anatomical regions (containing 90 per cent of all lesions) developed their lesions. During the conditioning period, 57 to 100 per cent of the lesions occurred during the middle third of the period and 70 per cent appeared in the half of the 24-day period, from the 8th–20th day. During the experimental period more lesions appeared earlier, 60 to 80 per cent occurring during the first half of the period and generally more than 50 per cent during the first quarter of the experimental period. In neither period was there evidence that any specific region developed its lesions at a significantly different time than any other region. None of the common superficial or deep lesions developed significantly earlier in one region than another. (See Appendix 2 for details.)

Table 6

Time of Appearance of Lesions

		Conditioning Period (%)			Experimental Period (%)			
Days		1-8	8-16	16-24	1-8	8-16	16-24	24-34
Toe	C	9	73	18	61	20	16	3
	E	22	57	22	50	24	20	6
Metatarsal	C	24	65	12	42	18	26	14
	E	16	71	13	54	9	16	19
Heel	C	0	100	0	43	14	22	21
	E	13	75	12	63	4	12	21
Rest	C	18	46	36	55	0	15	30
	E	22	33	45	61	8	8	23

8. Ability to March. From Table 7 it is apparent that the percentage loss by march lesions was very small and never exceeded 1.6 per cent. In both periods the loss in the experimental group was somewhat less.

Table 7

Ability to March

	Conditioning Period				Experimental Period			
	Mileage Per Foot*				Mileage Per Foot*			
Group	Planned	Actual	Loss by March Lesions	Loss by Non-March Lesions	Planned	Actual	Loss by March Lesions	Loss by Non-March Lesions
Control	(244) 100	98.6	0.4	1.0	(459) 100	90.5	1.6	7.9
Experimental	(244) 100	98.1	0.03	1.9	(459) 100	89.7	0.4	10.0

*Figures in parentheses indicate distance in miles. All other figures indicate percentage.

9. Effect of Marching on Shoes. Comparison of both types of shoes indicates that the worn shankless had the greater upward curvature of heel and toe.

Table 8 illustrates the effect of marching on the average measurements in the arch region of the shoe (as determined by X-ray). When new, both the standard service type and the shankless shoe approximated 3.3 cm. from shoe line to base (ground) line in the arch region, with the shankless shoe being about 1 mm. lower throughout. The latter can be explained by a relative inadequacy of "leatherboard-heel-seat-filler," and "ground cork filler," used between layers of sole as compensation for thickness of the missing steel shank. After use, both types were depressed in the arch region, but the old shankless shoe dropped somewhat more so that the shoe line in this shoe type was approximately 3 per cent closer to the ground than was that for the standard service shoe. The relationship between shoe and skin line was fairly constant, irrespective of whether the shoe was new, old, standard, or shankless.

Table 8

X-ray Studies

	Base to Sole				Base to Skin				Difference			
Type of Shoe	Heel	1 cm	2 cm	3 cm	Heel	1 cm	2 cm	3 cm	Heel	1 cm	2 cm	3 cm
New Standard	3.57	3.51	3.40	3.21	3.71	3.67	3.56	3.38	0.14	0.16	0.16	0.17
Old Standard	3.37	3.32	3.19	3.01	3.52	3.49	3.37	3.22	0.15	0.17	0.18	0.21
Sag	0.20	0.19	0.21	0.20	0.19	0.18	0.19	0.16	-	-	-	-
New Shankless	3.50	3.44	3.38	3.18	3.66	3.65	3.58	3.43	0.16	0.21	0.20	0.25
Old Shankless	3.21	3.15	3.06	2.90	3.36	3.34	3.29	3.15	0.15	0.19	0.23	0.25
Sag	0.29	0.29	0.32	0.28	0.30	0.31	0.29	0.28	-	-	-	-

III. RESULTS

B. Low Heel Shoes.

Forty-one subjects, divided into a control and experimental group, walked for 25 days during a conditioning period followed by a 27-day experimental period at the rates and distances per day indicated in Part A. The recruits had just completed their basic training (8 weeks) at Replacement Training Center, Fort Knox, Kentucky, where they had on occasion walked 11-12 miles per day. The physical data on the men, their feet, and the weather conditions encountered are in Table 9 and Fig. 7. The concrete route was used on two days because of the muddy

conditions of the other routes. During the second half of the experiment the temperature averaged considerably less than during the first half.

FIG 7

MAXIMUM DAILY TEMPERATURE AND HUMIDITY

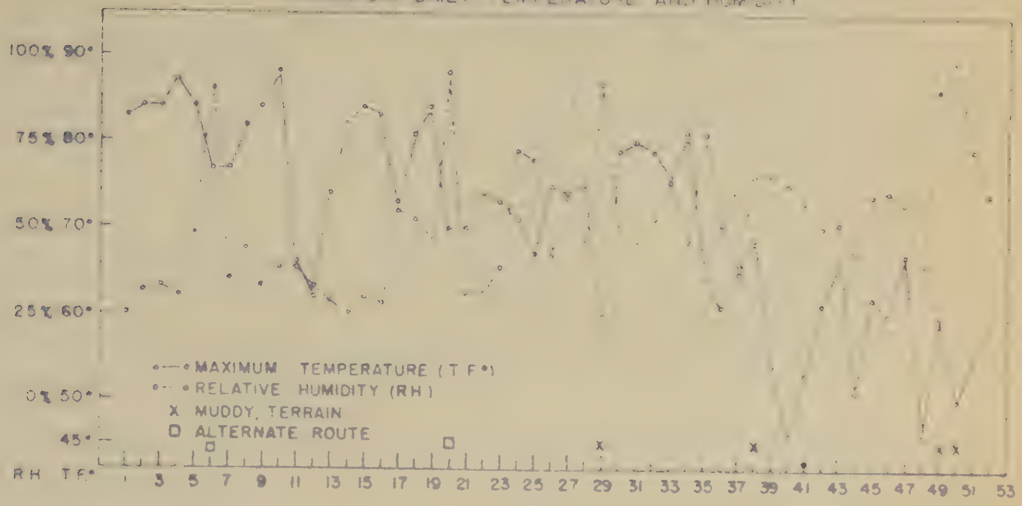


Table 9

Age, Height, and Weight Data

	Age (yrs.)		Height (cm.)		Weight (kilo)	
Group	Range	Average	Range	Average	Range	Average
Control	17-30	19.4	166.5-186.9	171.1	53.9-86.9	70.9
Experimental	17-25	20.5	162.1-188.9	176.6	51.2-97.6	70.6

1. Initial and Final Foot Inspection. There were no foot types in need of correctional shoes (Table 10). The initial foot lesions were few and trivial (78 per cent had epidermophytosis). In the final foot inspection there were only 3 lesions in the control group and 4 in the experimental group. All except one (a corn) were deep pains in the metatarsal, heel, and ankle region. (See Appendix 3.)

Table 10

Clinical Types of Feet

Type	Control Grouping	Experimental Grouping
"Normal"	19	17
Low Arch	1	0
Elevation of Toes	0	1
Asymmetrical Heel	0	1
Lean Foot	0	2

2. New Lesions Each Day. During each period the pattern of curves for the control and experimental groups is roughly similar (fig. 8 A). In both groups there are two temporary rises in incidence, a small one on the 10th day when the marching distance was increased to 13.5 miles per day, and a higher peak during the first 3 days of the experimental period (25th-28th day) when the new shoes were first being used. During these 3 days the new lesions averaged 14.3 and 15.6 per day and constituted 51 and 57 per cent, respectively, of all lesions occurring in the experimental period. However, both curves decrease within a few days to approximate the control values.

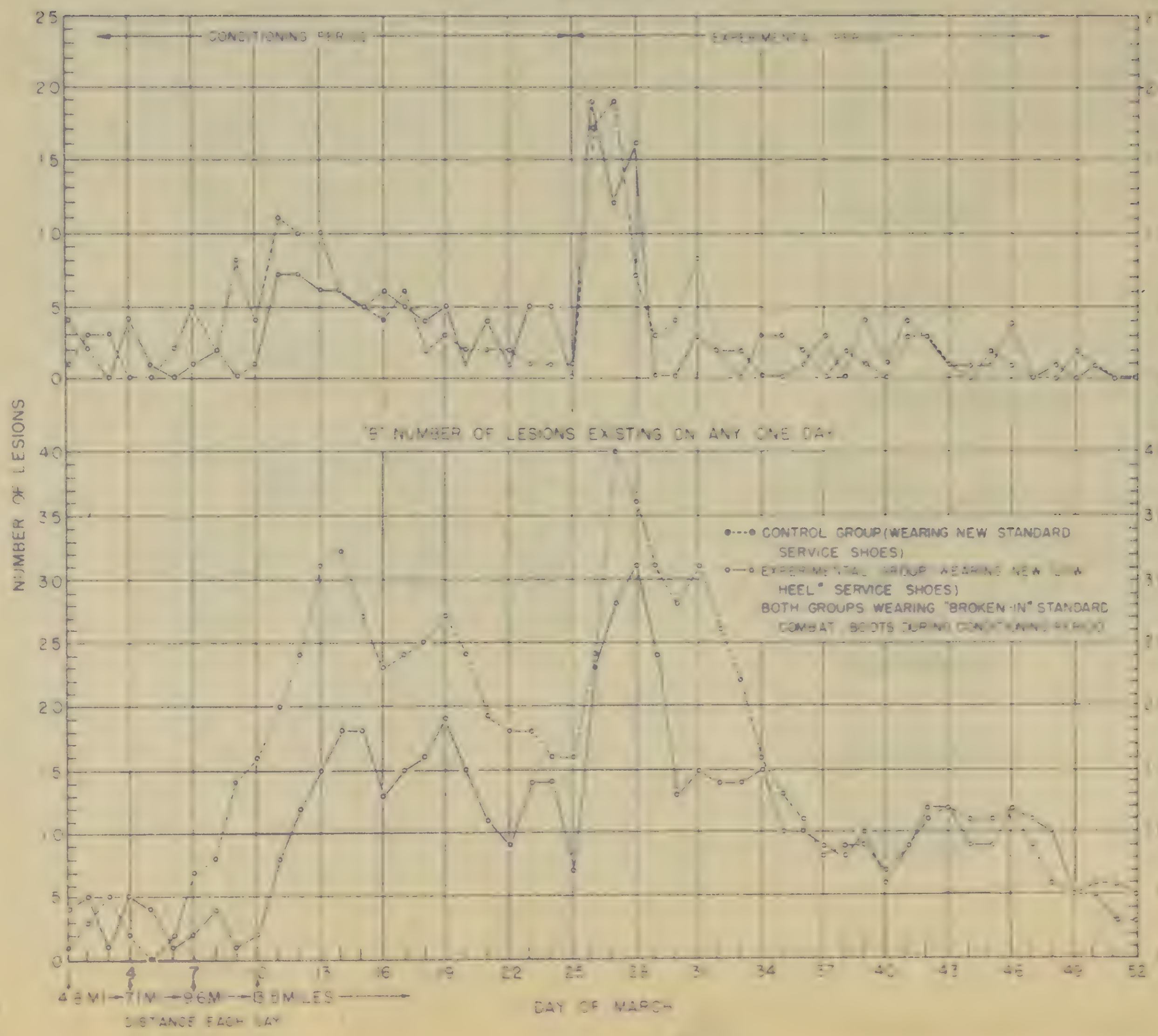
Table 11

Basic Data

	Conditioning Period		Experimental Period		Both Periods	
	C	E	C	E	C	E
Feet	40	42	40	42	80	84
Days	25	25	27	27	52	52
March Days of Lesions	402	233	409	336	811	569
Week-end Days of Lesions	120	59	106	96	226	155
Total Lesion Days	522	292	515	432	1037	724
New Lesions	94	82	84	82	178	164
Per Day*	3.8	3.1	3.1	2.9	3.4	3.0
Per Foot	2.3	2.0	2.1	2.0	2.2	2.0
Av. Duration Days**	5.5	3.6	6.1	5.3	5.8	4.5
Av. Duration Days Per Foot***	10	5.6	10.2	8.0	10.1	6.8
Total Lesions	402	233	409	336	811	569
Per Day*	16.0	9.3	15.1	11.7	15.6	11.0
Type, Superficial	53	39	50	51	103	90
Blister	38	28	23	12	61	40
Erythema	10	8	17	31	27	39
Callus	1	3	2	5	3	8
Corn	2	0	2	0	4	0
Rest	2	0	6	3	8	3
Type, Deep	41	43	34	31	75	74
Pain	35	37	25	30	60	67
Tenosynovitis	6	6	8	1	14	7
Rest	0	0	1	0	1	0
Type						
Objective	5	2	1	1		
Subjective	3	3	2	6		
Objective and Subjective	74	89	81	75		
Location						
Toe	35	26	23	16	58	42
Metatarsal	39	23	35	28	74	51
Heel	5	12	7	8	12	20
Rest	15	21	19	30	36	51

*Calculated in proportion to number of feet in group.
**Based on total lesion days.
***March lesion days divided by feet in group.

FIG 8



"A" NUMBER OF NEW LESIONS EACH DAY

"B" NUMBER OF LESIONS EXISTING ON ANY ONE DAY

During each period there was fairly good agreement between the two groups as to new lesions per day or per foot (Table 11).

FIG 9

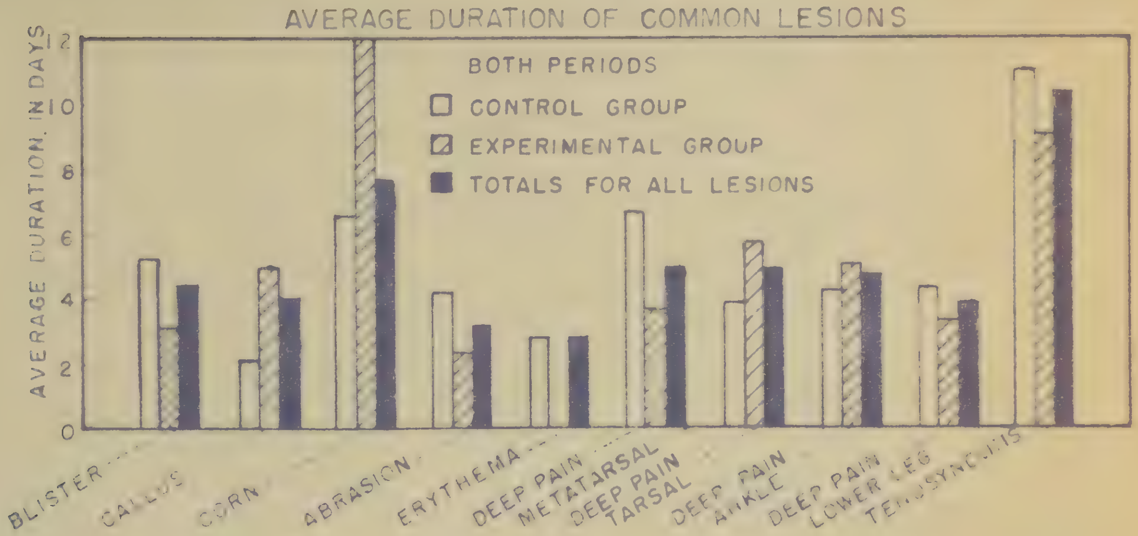


Fig. 9 illustrates that the common superficial and deep lesions lasted from 2 to 12 days with the average approximating 5 days with no great difference between the control and experimental groups. During the conditioning period the lesion days per foot (Table 11) were considerably greater in the control group, but during the experimental period this increased by 43 per cent for the experimental group, as compared to 2 per cent for the control group.

3. Total Number of Lesions Each Day. The curve for the control group (fig. 8 B is considerably higher (7th-34th day) than that for the experimental group but the patterns of the curves are roughly similar throughout, and elevations of the curves appear at the same times as in Fig. 8A. There is no definite correspondence between an increase in distance marched per day and the number of lesions per day. Each group had approximately 60 per cent more lesions existing in the first 10 days of the experiment than in the remaining 17 days. During the last 17 days of this period (29 per cent of the total mileage) the experimental group had an average of 8.4 lesions existing per day.

During the conditioning period the lesions per day in the control group were considerably more (16.0 versus 9.3), but this difference decreased considerably during the experimental period (15.1 versus 11.7) largely because of the increase in lesions in the experimental group (Table 11). (See Appendix 3 for details.)

4. Clinical Types of Lesions and Their Frequency. In both groups and periods 57 per cent of the lesions were superficial, 43 per cent were deep (Table 12). The incidence of both the superficial and deep lesions in the control and in the experimental groups compared favorably in both periods.

Of the superficial lesions, blisters (29%), erythema (19%), and the deep lesion, pain (37%), predominated in both periods and groups, and made up 85 per cent of all lesions. Blisters and erythema made up 86 per cent (52 and 34) of all superficial lesions, and deep pain constituted 86 per cent of the deep lesions. (See Appendix 3 for details.)

Table 12

Clinical Nature of Lesions

A. Percentages of Superficial and Deep Lesions

	Conditioning Period				Experimental Period				Both Periods			
	Superficial or Deep Lesions		Total Lesions		Superficial or Deep Lesions		Total Lesions		Superficial or Deep Lesions		Total Lesions	
	C	E	C	E	C	E	C	E	C	E	C	E
Type												
Superficial			56	48			59	62			58	55
Blister	71	72	40	34	46	24	28	15	59	44	35	24
Erythema	19	20	11	10	34	60	20	37	25	44	15	24
Callus	2	8	1	4	4	10	2	6	3	9	2	5
Corn	4	0	2	0	4	0	2	0	4	0	2	0
Rest	4	0	2	0	12	6	7	4	8	3	4	2
Deep			44	52			40	38			42	45
Pain	85	86	37	45	73	97	30	37	80	90	34	41
Tenosynovitis	15	14	7	7	24	3	9	1	19	10	8	4
Rest	0	0	0	0	3	0	1	0	1	0	0	0

B. Percentages of Objective and Subjective Lesions

	Conditioning Period		Experimental Period		
	C	E	C	E	
Type					
Objective	6	2	1	1	
Subjective	4	3	2	7	
Obj. & Subj.	90	95	96	92	

5. Anatomical Location of Lesions. The toe (29%), metatarsal (37%), and heel (9%) regions contained 75 per cent of all lesions. For these regions the relative values for the control versus the experimental groups remained fairly constant in both periods (Table 13). Almost all lesions in the toe region were superficial, the values for the periods and groups varying only from 94 to 100 per cent. In the metatarsal and heel regions 54 and 51 per cent, respectively, of the lesions were superficial. During the experimental period the percentage increased for the control group in both regions, while for the experimental group the percentage increased in the heel region and decreased in

the metatarsal region. (Further details are in Appendix 3.)

Table 13

Location of Lesions

	Conditioning Period				Experimental Period				Both Periods			
	Superficial Lesions--%		All Lesions--%		Superficial Lesions--%		All Lesions--%		Superficial Lesions--%		All Lesions--%	
	C	E	C	E	C	E	C	E	C	E	C	E
Toe	94	96	37	32	96	100	28	20	95	98	33	26
Metatarsal	51	35	42	28	66	61	42	34	58	47	42	31
Heel	0	42	5	15	29	75	8	10	17	55	6	12
Ankle	0	13	3	10	17	55	14	24	12	43	9	17
Rest	0	0	13	15	15	10	8	12	5	4	10	14

6. Time of Appearance of Lesions by Region and Type. Most of the lesions appeared during the middle half of the conditioning period in both groups, averaging 80 per cent for the control group and 68 per cent for the experimental group (Table 14). During the experimental period 70 per cent and 63 per cent of the lesions in the control and experimental groups, respectively, appeared during the first 7 days. There was no indication that any specific region developed its lesions at a different time from any other region, or that there was a preferential region for early development of the common superficial or deep lesions. (See Appendix 4.)

Table 14

Time of Appearance of Lesions

Days		Conditioning Period (%)			Experimental Period (%)		
		1-6	6-19	19-25	1-7	7-20	20-27
Toe	C	6	89	6	74	26	0
	E	19	46	35	63	32	6
Metatarsal	C	18	72	10	66	29	6
	E	13	74	13	72	18	11
Heel	C	0	100	0	70	15	15
	E	8	75	17	63	25	12
Ankle	C	0	100	0	67	25	8
	E	12	75	13	70	25	5
Rest	C	0	89	11	79	16	5
	E	10	72	18	57	40	3

7. Ability to March. As in the experiment in which shankless shoes were worn, the mileage lost by march lesions was quite small in both groups and periods, the average for control and experimental groups being 1.1 per cent versus 1.0 per cent (Table 15).

Table 15

Ability to March

	Conditioning Period				Experimental Period			
	Mileage Per Foot*				Mileage Per Foot*			
Group	Planned	Actual	Loss by March Lesions	Loss by Non-March Lesions	Planned	Actual	Loss by March Lesions	Loss by Non-March Lesions
Control	(280)100	95.9	1.6	2.5	(364.5)100	95.8	1.0	3.2
Experimental	(280)100	97.5	0.8	1.7	(364.5)100	95.2	1.4	3.4

*Figures in parentreses indicate distance in miles. All other figures indicate percentage.

8. Effect of Marching on Shoes. Visual inspection and manipulation of the two shoe types revealed very little difference as to general condition, degree of curvature of heel and toe, and flexibility of shoe.

IV. DISCUSSION

The incidence of tenosynovitis in both groups of the experiment with low-heel shoes deserves explanation. During the conditioning period, each group had 6 cases of traumatic tenosynovitis distributed in the metatarsal, ankle, and lower leg regions. During the experimental period, 8 cases of tenosynovitis occurred in the control group as compared to 1 in the experimental group. These lesions are believed to be caused by the "broken in" combat boots worn during the conditioning period, since (1) the preceding experiment had only one such case, (2) removal of a pressure point from the cuff of the boot caused symptomatic improvement, and (3) most of the lesions in the experimental period represented reactivation of old lesions.

Except for minor differences, the results obtained using shankless shoes and low-heel shoes are similar and will be considered together.

It is believed that the initial period achieved adequate conditioning of the subjects and established their comparability. In this period, the control and experimental groups showed comparable susceptibility to the development of new lesions, and the nature and location of the lesions produced failed to indicate significant differences in the reaction patterns for the two groups. During the last few days of the conditioning period, the declining incidence of specific lesions, together with the daily observation that the subjects no longer showed

evidence of muscular fatigue or soreness either generally or in the legs and feet after marches, indicated that for practical purposes conditioning had been achieved. Therefore, any actual further statistically significant divergence in lesions in the two groups in the experimental period should be attributed to the different principles of support embodied in the two shoes.

The number of new lesions per day and the total lesions existing each day increased considerably in both groups during the first few days of the experimental period. The increments were statistically significant. However, this can be attributed to the "breaking in" process of the stiff new shoes, since each group wearing different shoe types showed this same response and no significant difference existed between the group wearing standard service shoes and those with shankless shoes or with low heels. For the remainder of the experimental period the incidence of lesions in the two groups was roughly similar, the values approximated or were less than those in the latter stages of the conditioning period, and the types and locations of the lesions were essentially the same for the two groups. Finally, there was no significant difference between the effect of the two experimental shoe types on the foot health of the marching troops as evidenced by the type, number, duration, location, and severity of the lesions and the ability of the troops to march.

Therefore, *under the conditions of these experiments*, the absence of a steel shank in a shoe or the reduction in height of the heel is not detrimental to the health of the feet of marching troops. However, it remains to be determined by how much the shank removal actually affected the support of the feet and whether the tests used for both types of experimental shoes were adequate to determine the state of foot health. As shown by X-ray, although both standard and shankless shoes were somewhat lower in the arch region after the march period, the latter were only about 3 per cent lower than the standard shoe, certainly not a large difference. On the other hand, comparison of both types of shoes indicated the worn shankless type to have a greater upward curvature of the heel and toe, and manual flexing showed that the worn shankless type was appreciably more flexible in the sole and probably less capable of support. However, accurate gauging of this factor is impossible by manual means, and the X-ray measurements are based on a "static shoe" when the subject was standing and cannot be taken as evidence of what takes place in a "shoe in action."

No tests were made to determine what dynamic or static changes, if any, took place in the bones and their relationship in the feet. It is obvious that such changes might well exist and contribute to the pathology of the feet. Therefore, the possibility must be entertained that more critical tests might well reveal significant alterations in the feet at the mileage walked in these experiments, or that considerable prolongation of the mileage per foot might bring to light correlated changes in foot physiology and in the shoes worn as revealed by present or additional tests.

V. CONCLUSIONS

Tests were made of the value to foot health of support in the arch and heel of the feet of marching troops. The control shoes, army service shoe, Type III, and combat boots were compared with experimental shoes with a low heel, and with those in which steel shank support in the longitudinal arch had been removed.

During the first few days of the experimental period, when the shoes were new, the highest incidence rates of lesions were reached for both control and experimental groups.

There was no essential difference between the effect of the control and experimental shoes on the foot health of marching troops as evidenced by the frequency, type, duration, distribution, time of onset, and severity (march time lost due to lesions) of the clinical lesions present.

In the shankless shoe experiment, the superficial lesions constituted 79 per cent of all lesions, the deep lesions 21 per cent; in the low-heel experiment, superficial lesions made up 57 per cent of all lesions. The most common lesions were blisters, erythema, callus, and deep pain. Most lesions were located in the toe, metatarsal, and heel regions.

After the march period, both worn standard service and experimental shankless shoes were somewhat lower in the arch region, with the shankless shoe about 3 per cent lower. The shankless shoe had a considerably greater upward curvature of heel and toe, and a more flexible sole with manual manipulation. This factor gave the shankless shoe a less favorable appearance and possibly had a deleterious effect on the durability of the shoe.

What more critical tests involving dynamic or static changes in bones and their relationship at the same or greater marching distances will reveal, remains to be determined.

VI. RECOMMENDATIONS

That further studies in support be carried out, testing the other regions of support and their possible combinations.

That these investigations should also include studies of the dynamic foot-shoe relationship, using motion picture X-rays.

VII APPENDIX

APPENDIX

A. DAILY INCIDENCE AND TYPE OF CLINICAL LESIONS

Conditioning Period—Control Group

Experimental Period—Control Group

Day of Search

Miles Per Day

Type of Lesion

Superficial

Blister

Erythema

Callus (painful)*

Corn (painful)*

Abrasion

Contusion

Ingrown Nail*

Plantar Warts*

Total

Deep

Deep Pain

Sprain

Tenosynovitis

Total

Group Total

Total Lesions Per Day

Conditioning Period—Experimental Group

Experimental Period—Experimental Group

B. INCIDENCE AND LOCATION OF CLINICAL LESIONS

Conditioning Period

Experimental Period

Ingrown Nails

Plantar Warts

Deep Pain

Sprain

Totals

Totals

*Recorded only when symptomatic.

[illegible] tion in the initial first [illegible]

At the final inspection there were an additional [illegible]

APPENDIX 2

RELATION OF AREA INVOLVED TO ONSET DAY OF LESION

Conditioning Period—Control Group

Day of March		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Miles Per Day		4.8				7.1				5.5					3.5											
Region of Lesion																										
Toe I		.	.	.	.	1	.	1	.	.	2	.	1	.	1	.	.	1	.	.	3	.	.	.	.	10
Toe II		.	.	.	.	.	.	.	.	1	.	1	1	1	2	.	1	1	2	.	3	1	.	2	1	17
Toe III		.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	1	.	3
Toe IV		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1
Toe V		.	.	.	.	.	1	1	.	.	.	.	.	1	.	2	1	.	2	1	1	1	2	.	.	13
M.T. I	DH	.	1	3	2	1	.	.	.	2	.	.	5	.	.	1	2	.	1	1	1	1	.	.	.	21
	MS	.	.	1	.	.	.	.	.	.	.	1	1	.	.	.	.	.	1	.	.	.	.	.	.	4
M.T. II	DH	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	1	1	.	4
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
M.T. III	DH	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
M.T. IV	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
M.T. V	DH	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
2 or more	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1
2 or more	MS	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1
Tarsal		.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	1	.	.	.	.	1	.	4
Heel		.	.	.	.	.	.	.	.	.	1	1	.	.	3	.	1	.	1	.	1	.	.	.	.	8
Ankle		.	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	1	.	3
Low Leg		.	.	.	1	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	3
Knee		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1
Totals		3	2	4	4	1	1	2	8	4	4	5	10	4	7	4	5	5	9	2	9	4	3	5	1	97

Experimental Period—Control Group

Conditioning Period—Experimental Group

Day of March		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Toe I		.	.	.	.	.	.	.	.	.	.	.	3	.	1	.	.	.	.	.	1	.	1	.	.	6
Toe II		.	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	2	.	1	.	.	.	1	.	6
Toe III		.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Toe IV		.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	1	.	3
Toe V		.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	2	6
M.T. I	DH	1	1	.	1	.	.	1	.	.	1	.	.	.	2	1	1	.	.	3	.	1	.	.	1	14
	MS	.	.	.	.	.	.	.	.	2	.	.	1	.	1	.	1	.	.	.	.	.	.	.	.	5
M.T. II	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.	.	1	.	2	.	.	.	5
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
M.T. III	DH	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	2
	MS	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	2
M.T. IV	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
M.T. V	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	1
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
2 or more	DH	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	2
2 or more	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Tarsal		.	1	.	.	.	1	.	.	2	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	6
Heel		.	.	.	1	.	.	.	.	.	2	.	.	.	1	.	2	.	.	1	.	1	.	.	.	8
Ankle		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Low Leg		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	2
Knee		.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Totals		1	2	1	1	6	7	1	1	1	5	6	4	4	8	1	7	2	3	6	3	5	1	2	3	71

Experimental Period—Experimental Group

DH—Distal Head
MS—Mid-shaft
M.T.—Metatarsal

APPENDIX 3

A. DAILY INCIDENCE AND TYPE OF CLINICAL LESIONS

Conditioning Period—Control Group

Day of March		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
Miles Per Day		4.5				7.1				9.5				13.5													
Type of Lesion																											
Superficial																											
Blister	[illegible]	1	.	1	.	.	.	1	1	4	2	1	5	5	3	1	4	4	1	2	.	.	.	1	1	.	38
Erythema	[illegible]	.	.	.	.	.	2	3	.	1	.	1	1	.	1	.	.	.	.	1	.	.	.	.	.	.	10
Callus*	2	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Corn*	1	.	1	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Abrasion	[illegible]	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Contusion	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Ingrown Nail*	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Plantar Wart*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1
Total		1	0	1	0	0	2	4	1	5	3	3	6	5	4	2	4	4	1	3	0	0	0	1	1	0	52
Deep																											
Deep Pain	0	.	1	2	.	.	.	1	1	3	1	7	3	4	2	2	.	1	1	.	1	2	2	.	.	1	35
Sprain	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Tenosynovitis	0	.	.	.	.	.	.	.	.	.	.	1	1	1	.	1	.	1	.	.	1	.	.	.	.	.	6
Total		0	1	2	0	0	0	1	1	3	1	8	4	5	2	3	0	2	1	0	2	2	2	0	0	1	41
Group Total		1	1	3	0	0	2	5	2	8	4	11	10	10	6	5	4	6	2	3	2	2	2	1	1	1	93
Total Lesions Per Day		1	3	5	2	0	2	7	8	14	16	20	21	31	32	27	23	24	25	27	24	19	18	18	16	16	
Conditioning Period—Experimental Group																											
Superficial																											
Blister	2	2	.	.	1	.	.	.	.	.	1	2	2	3	2	1	2	3	1	.	.	2	1	3	2	.	28
Erythema	0	2	.	.	.	.	.	.	.	.	.	3	2	1	.	.	.	.	.	.	.	.	.	.	.	.	8
Callus*	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	1	.	.	.	3
Corn*	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Abrasion	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Contusion	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Ingrown Nail*	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Plantar Wart*	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Total		4	0	0	1	0	0	0	0	0	1	5	4	4	2	1	2	3	3	0	0	2	2	3	2	0	39
Deep																											
Deep Pain	0	.	2	.	2	1	.	1	2	.	.	1	3	2	3	4	4	2	1	5	1	.	.	.	3	.	37
Sprain	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
Tenosynovitis	0	.	.	.	1	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	1	.	2	.	.	6
Total		0	2	0	3	1	0	1	2	0	0	2	3	2	4	4	4	2	1	5	1	1	0	2	3	0	43
Group Total		4	2	0	4	1	0	1	2	0	1	7	7	6	6	5	6	5	4	5	1	3	2	5	5	1	82
Total Lesions Per Day		4	3	4	5	4	1	2	4	1	4	8	12	15	18	18	13	14	16	19	15	11	9	14	14	7	

Experimental Period—Control Group

Day of March	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58		Total
Miles Per Day	23.5																																		
Type of Lesion																																			
Superficial																																			
Blister	5	5	5	2	.	2	.	.	.	1	1	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.							0	23
Erythema	8	2	1	.	1	2	.	.	1	1	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	17
Callus*	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	2
Corn*	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	2
Abrasion	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.							1	3
Contusion	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	1
Ingrown Nail*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	0
Plantar Wart*	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	2
Total	15	10	6	2	1	5	1	0	1	3	1	0	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0								50
Deep																																			
Deep Pain	1	9	.	1	3	1	1	.	2	.	1	.	.	.	.	1	1	.	.	2	.	.	.	1	1	.	.							0	25
Sprain	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.							0	1
Tenosynovitis	1	.	1	.	.	2	.	.	.	.	.	.	.	1	.	1	1	.	.	.	1	.	.	.	.	.	.							0	8
Total	2	9	1	1	3	3	1	0	2	0	1	0	0	1	0	2	2	0	0	2	1	0	0	2	1	0	0								34
Group Total	17	19	7	3	4	8	2	0	3	3	2	0	2	1	0	3	3	1	0	2	1	0	0	2	1	0	0								84
Total Lesions Per Day	24	40	30	31	28	31	26	22	16	13	11	8	9	9	7	9	[illegible]	12	11	11	12	9	6	5	5	3	3								
Experimental Period—Experimental Group																																			
Superficial																																			
Blister	2	1	2	.	.	1	.	1	.	.	.	1	.	.	.	1	1	.	.	.	2	.	.	.	.	.	.							0	12
Erythema	8	8	8	.	.	1	.	.	.	.	1	.	.	1	.	1	.	.	.	.	1	.	1	.	1	.	.							0	31
Callus*	1	1	.	.	.	.	2	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.							0	5
Corn*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							1	0
Abrasion	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	0
Contusion	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	1
Ingrown Nail*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.							0	1
Plantar Wart*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.							0	1
Total	11	10	11	0	0	2	2	1	0	0	1	1	0	1	1	2	1	1	1	0	3	0	1	0	1	0	0							0	51
Deep																																			
Deep Pain	8	2	5	.	.	1	.	1	2	.	.	2	.	3	.	2	2	.	.	1	1	.	.	.	.	.	.							3	30
Sprain	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	0
Tenosynovitis	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.							0	1
Total	8	2	5	0	0	1	0	1	3	0	0	2	0	3	0	2	2	0	0	1	1	0	0	0	0	0	0								31
Group Total	19	12	16	0	0	3	2	2	3	0	1	3	0	4	1	4	3	1	1	1	4	0	1	0	1	0	0								82
Total Lesions Per Day	23	29	32	24	13	15	14	11	15	10	10	9	8	10	6	9	12	12	9	9	12	11	10	5	6	6	5								

B. INCIDENCE AND LOCATION OF CLINICAL LESIONS

Conditioning Period

Region		Blister C	Blister E	Erythema C	Erythema E	Callus* C	Callus* E	Corn* C	Corn* E	Abrasion C	Abrasion E	Contusion C	Contusion E	Ingrown Nail* C	Ingrown Nail* E	Plantar Wart* C	Plantar Wart* E	Deep Pain C	Deep Pain E	Sprain C	Sprain E	Tenosynovitis C	Tenosynovitis E	Totals C	Totals E	Totals C & E
Toe I		5	8	1	1	.	2	.	.	.	.	.	.	.	.	.	.	2	1	.	.	.	.	8	12	20
Toe II		10	4	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	6	16
Toe III		2	1	1	2	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	4	3	7
Toe IV		3	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	1	5
Toe V		7	4	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	9	4	13
M.T. I	DH	7	6	5	1	1	1	1	.	1	.	.	.	.	.	.	.	4	7	.	.	1	.	20	15	35
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	1	.	.	1	.	6	1	7
M.T. II	DH	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	1	.	.	.	.	5	1	6
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	0
M.T. III	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	0	1
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	0
M.T. IV	DH	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	2	2	4
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	0	1
M.T. V	DH	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	0	1
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	0
2 or more	DH	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	2	4	.	.	.	.	3	4	7
2 or more	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	0
Tarsal		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	.	.	.	.	3	2	5
Heel		.	4	.	1	.	.	.	.	.	.	.	.	.	.	.	.	2	2	.	.	3	5	5	12	17
Ankle		.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	3	6	.	.	.	1	3	8	11
Lower Leg		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	4	.	.	1	.	8	4	12
Knee		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	7	.	.	.	.	1	7	8
Thigh		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	0
Totals		38	28	10	8	1	3	2	0	1	0	0	0	0	0	1	0	35	37	0	0	6	6	94	82	176

Experimental Period

Region		Blister C	Blister E	Erythema C	Erythema E	Callus* C	Callus* E	Corn* C	Corn* E	Abrasion C	Abrasion E	Contusion C	Contusion E	Ingrown Nail* C	Ingrown Nail* E	Plantar Wart* C	Plantar Wart* E	Deep Pain C	Deep Pain E	Sprain C	Sprain E	Tenosynovitis C	Tenosynovitis E	Totals C	Totals E	Totals C & E
Toe I		2	1	1	3	.	.	.	.	.	.	.	.	.	.	2	1	1	.	.	.	.	.	6	5	11
Toe II		4	3	1	1	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	6	11
Toe III		4	2	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	2	8
Toe IV		1	.	.	.	.	.	1	.	1	.	.	.	.	1	.	.	.	.	.	.	.	.	3	1	4
Toe V		3	.	.	1	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	3	2	5
M.T. I	DH	5	4	4	4	.	.	.	.	.	.	.	.	.	.	.	.	3	3	.	.	1	1	13	12	25
	MS	.	1	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	2	.	.	1	.	3	3	6
M.T. II	DH	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	4	0	4
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	0	1
M.T. III	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	1	1	2
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	0
M.T. IV	DH	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	2	3
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	0
M.T. V	DH	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	2	1	3
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	0	1
2 or more	DH	1	.	7	.	.	2	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	9	3	12
2 or more	MS	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	0	6	6
Tarsal		.	.	.	1	.	.	.	.	1	.	.	.	.	.	.	.	3	5	.	.	.	.	4	6	10
Heel		.	1	1	5	1	.	.	.	.	.	.	.	.	.	.	.	5	2	.	.	.	.	7	8	15
Ankle		.	.	2	11	.	.	.	.	.	.	.	.	.	.	.	.	6	9	1	.	3	.	12	20	32
Lower Leg		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	3	.	.	1	.	2	3	5
Knee		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	0	1	1
Thigh		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	0	1
Totals		23	12	17	31	2	5	2	0	3	0	1	1	0	1	2	1	25	30	1	0	8	1	84	82	166

*Recorded only when symptomatic.

DH—Distal Head
MS—Mid-shaft
M.T.—Metatarsal

C—Control Group
E—Experimental Group

APPENDIX 4

RELATION OF AREA INVOLVED TO ONSET DAY OF LESION

Conditioning Period--Control Group / Experimental Period--Control Group

Region of Lesion		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total	26	27	28
Toe I		.	1	.	.	.	.	1	.	1	1	.	1	.	.	.	1	1	1	.	.	.	.	.	.	.	8	2	2	.
Toe II		1	.	.	.	.	.	.	1	1	.	1	1	.	.	.	1	1	.	1	.	.	.	1	1	.	10	1	.	1
Toe III		.	.	.	.	.	.	.	.	.	.	1	1	.	.	1	1	.	.	.	.	.	.	.	.	.	4	.	2	1
Toe IV		.	.	.	.	.	.	.	.	.	1	.	1	1	.	.	.	1	.	.	.	.	.	.	.	.	4	1	.	1
Toe V		.	.	.	.	.	.	.	.	1	.	.	.	2	3	1	.	1	.	1	.	.	.	.	.	.	9	.	2	.
M.T. I	DH	.	2	1	.	.	1	2	.	2	.	1	1	2	2	.	.	1	.	.	1	2	.	.	.	.	20	4	1	1
	MS	.	.	.	.	.	.	.	.	.	.	1	2	1	1	.	.	.	.	.	1	.	.	.	.	.	6	.	1	1
M.T. II	DH	.	.	.	.	.	.	1	.	.	1	2	.	.	.	.	1	.	.	.	.	.	.	.	.	.	5	1	.	1
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	1
M.T. III	DH	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
M.T. IV	DH	.	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	.	.	.
M.T. V	DH	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
2 or more	DH	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	3	[illegible]	.	.
2 or more	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
Tarsal		.	.	.	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	3	1	1	.
Heel		.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	1	.	.	.	.	.	.	.	.	3	.	1	.
Ankle		.	.	.	.	.	.	.	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	1	[illegible]	.
Low Leg		.	.	.	.	.	.	.	1	.	.	1	.	1	.	1	.	.	.	.	.	.	1	.	.	.	8	.	.	.
Knee		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.
Thigh		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	1	.
Totals		1	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	4	11	[illegible]	[illegible]	6	5	4	6	2	[illegible]	[illegible]	2	[illegible]	[illegible]	1	1	94	17	19	[illegible]

Conditioning Period--Experimental Group / Experimental Period--Experimental Group

Region of Lesion		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total	26	27	28
Toe I		.	.	.	.	.	.	1	.	.	.	1	.	1	1	.	.	.	1	.	1	.	1	1	.	.	12	.	.	2
Toe II		1	.	.	1	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	1	.	.	.	6	2	1	1
Toe III		1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	[illegible]	.	1	.
Toe IV		.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	[illegible]	.	.	.
Toe V		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	2	1	.	.	4	1	[illegible]	1
M.T. I	DH	.	.	.	.	.	.	.	.	.	.	.	3	1	1	1	.	2	2	.	.	.	1	1	.	.	15	[illegible]	[illegible]	1
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1
M.T. II	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
M.T. III	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
M.T. IV	DH	.	.	.	1	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	2	1	.	.
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
M.T. V	DH	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	.
2 or more	DH	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	2	.	.	.	.	.	.	4	1	.	.
2 or more	MS	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	3	2	1
Tarsal		.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	2	.	1	.
Heel		.	.	.	1	.	.	.	.	.	.	1	1	.	1	1	2	2	.	1	.	1	.	.	1	.	12	1	.	1
Ankle		.	.	.	1	.	.	.	1	.	.	2	.	.	.	.	2	.	.	1	1	.	.	.	.	.	8	6	5	2
Low Leg		.	.	.	.	1	.	.	.	.	.	1	1	.	.	.	.	.	.	1	.	.	.	.	.	.	4	.	.	1
Knee		.	.	.	.	.	.	.	.	.	.	.	2	1	.	.	2	.	1	.	.	.	.	.	1	.	7	1	.	.
Totals		[illegible]	[illegible]	[illegible]	4	1	0	1	2	0	1	7	8	6	6	5	6	5	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	82	17	12	15

DH--Distal Head
MS--Mid-shaft
[illegible]

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No-11

PLASTIC EAR MOLD FOR COMMUNICATIONS EQUIPMENT*

by

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from

Medical Department Field Research Laboratory
Fort Knox, Kentucky, 30 September 1947

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*Sub-project under Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks. (MDFRL-57). Approved by CG, ASF, 31 May 1946.

No. 11

Project No. 57-5
MEDEA

30 September 1947

ABSTRACT

PLASTIC EAR MOLD FOR COMMUNICATIONS EQUIPMENT

OBJECT

To investigate the local physiological implications of the utilization of plastic ear molds for communications equipment. The problem included (1) possible injury to the ear from physical trauma, blast concussion dynamics, discordant radio reception and manual manipulation of molds; (2) consideration of the comfort of such molds in extreme cold and hot climates; (3) consideration of the production of a universal type plastic ear mold for all subjects.

RESULTS AND CONCLUSIONS

Moderate physical blows to an inserted mold produced pain and erythema within the external auditory canal. Because of the rigid structure of the subject device, a more severe or heavier blow might possibly fracture the bony structure of the external auditory canal.

The plastic ear mold HS-30 receiver headset combination, in which the mold canal is occluded, afforded a partial protection against temporary hearing loss from concussion of gunfire but this protection disappeared when the ear mold was used without the attached HS-30 receiver headset, in which the mold canal was patent.

Temporary hearing loss from field radio communication was less with the plastic ear mold HS-30 receiver headset combination than with the tank headset H16/U. A greater signal to noise ratio of field radio communication was noted with the plastic ear mold HS-30 receiver headset combination than with the tank headset H16/U because a lower volume control setting for adequate reception was required.

Moderate manual manipulation of the plastic ear mold or its use in extremes of environmental temperature produced no injury to the ear.

A satisfactory universal plastic ear mold was not obtained because of the variations in anatomical characteristics of the individual ear.

RECOMMENDATIONS

The plastic ear mold is not recommended for general use, but may be suitable for individual use in specialized situations.

Submitted by:
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PLASTIC EAR MOLD FOR COMMUNICATIONS EQUIPMENT

I. INTRODUCTION

This project was initiated to investigate the local physiological implications of the utilization of plastic ear molds for communications equipment. The problem included (1) investigation of possible injury to the ear from physical trauma, blast concussion dynamics, discordant radio reception and manual manipulation of molds; (2) consideration of the comfort of such molds in extreme cold and in hot climates; (3) consideration of the production of a universal type plastic ear mold for all subjects.

This report completes the investigation directed by the Office of The Surgeon General, letter dated 12 September 1946, MEDDH, "Plastic ear molds for communications equipment."

II. EXPERIMENTAL

A. Apparatus and Methods

The basic apparatus used in the above tests consisted of plastic ear molds (Fig. 1) fabricated at this laboratory according to the method outlined by Lt. Col. G. A. McCracken (1) and a standard receiver headset, HS-30, adapted for rapid fastening to the plastic ear mold.

To determine possible injury to the ear from physical blows, pressure was applied with the fingers at various angles to the body of the molds inserted into the ears of 8 subjects. Upon complaint of discomfort or pain, otoscopic examinations were performed. An otoscopic examination was performed on one subject 24 hours after he received an accidental blow over both ears while wearing plastic ear molds under a thin cotton helmet.

Hearing loss from concussion of gunfire while wearing plastic ear molds was determined in the field at Fort Knox, Kentucky. Normal base line audiograms of 5 subjects were compared with audiograms on the same subjects taken immediately following exposure to the blast concussion of 3 successive rounds of a 90 mm. gun with the subject 20 feet behind and facing the muzzle. A Standard Maico audiometer with 10 pure tone frequencies from 128 to 11,584 cycles per second was used for measurement of hearing loss. The experiment was done in triplicate under each of the following conditions: (1) with the plastic ear mold and HS-30 combination in right ear and the left ear open; (2) with the plastic ear mold and HS-30 combination in left ear with the right ear open; (3) with plastic ear molds in both ears without the attached receivers (mold canal patent).

Hearing loss and rate of recovery to the normal base line audiogram under field radio communication were determined in the field at Task Force Furnace, Yuma, Arizona. The radio receiver and transmitter were of the BC-620 type. Immediately following a 2 hour period of radio communication, audiograms of 3 subjects were taken and again at 30 minute, 2, 4, and 24 hour intervals. Duplicate tests were done on each subject to compare plastic ear mold HS-30 combination with the standard tank headset H16/U. Signal readability was maintained constant by the subject when using the two types of headsets by adjustment of the receiver volume control.

FIG. 1 PLASTIC EAR MOLD

Possible damage to the ear from manual manipulation of the plastic ear mold was determined in 8 subjects. Separate auditory histories and otoscopic examinations were done before and after each of the following test conditions: (1) 48 hours of continuous wearing of the molds, the subject inserting and removing the molds without prior instruction; (2) a daily 8 hour period for 5 consecutive days, with the molds correctly inserted and removed every half hour; (3) a daily 8 hour period of continuous wearing of molds on 5 consecutive days, with the molds correctly inserted and removed.

Comfort of the plastic ear mold, in both arctic and desert temperatures was evaluated.* Three subjects wore the plastic ear molds under arctic conditions at Fort Churchill, Canada during the winter 1946-1947; 4 subjects wore them an average of 4 hours daily for a period of 2 weeks at Task Force Furnace, Yuma, Arizona, during June-July 1947.

In considering the possibility of developing a universal plastic ear mold each of 10 subjects received trial fittings of 10 different pairs of plastic ear molds made to fit other subjects but not specifically designed for these subjects. Their degree of fit, comfort and acoustic seal was ascertained.

B. RESULTS

Physical blows produced various effects on the ears into which plastic ear molds were inserted. Moderate pressure, on the body of the inserted mold, in the direction of the auditory canal produced no pain or evidence of injury (otoscopic examination); at all other angles, it produced discomfort. Heavy pressure produced pain and a resultant transient erythema of the auditory canal (otoscopic examination). Moderate erythema of the external auditory canals was noted in the subject who had received an accidental blow to both ears 24 hours prior to otoscopic examination.

Audiometric curves, following exposure to blast concussion, showed a partial protection against temporary deafness with the subject wearing the plastic ear mold HS-30 receiver headset combination but this protection disappeared when the plastic ear molds were worn without the attached HS-30 receiver headset, that is, with the mold canal patent (cf. Figs. 2 and 3).

Tests under field radio communication showed that a lesser temporary hearing loss was produced when using the plastic ear mold HS-30 receiver headset combination than when using the tank headset H16/U. However, audiograms with either type of headset approximated the control levels within 4 hours after the 2 hour period of radio communication (Fig. 4). For the same readability of reception, the volume control of the receiver averaged one fourth open when using the plastic ear mold HS-30 combination as compared to one third open when using the tank headset H16/U.

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* Fort Churchill, Canada, day temperature range -20° to -40° F.
Yuma, Arizona, day temperature range 100° to 120° F. June-July.

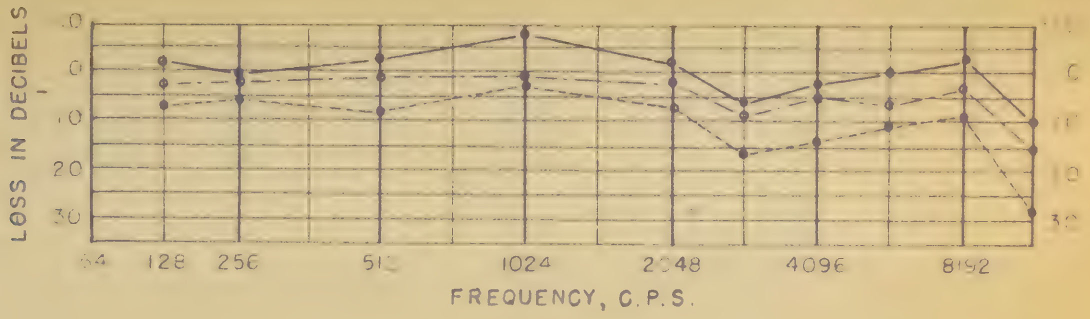

FIG. 2. AVERAGE AUDIOGRAMS OF 5 SUBJECTS BEFORE AND IMMEDIATELY AFTER 3 SEPARATE EXPOSURE PERIODS TO 3 SUCCESSIVE ROUNDS OF 90 MM GUN BLAST

LEGEND

AVERAGE NORMAL AUDIOGRAMS

PLASTIC EAR MOLD & HS-30 RECEIVER HEADSET

WITHOUT PLASTIC EAR MOLDS (EARS OPEN)

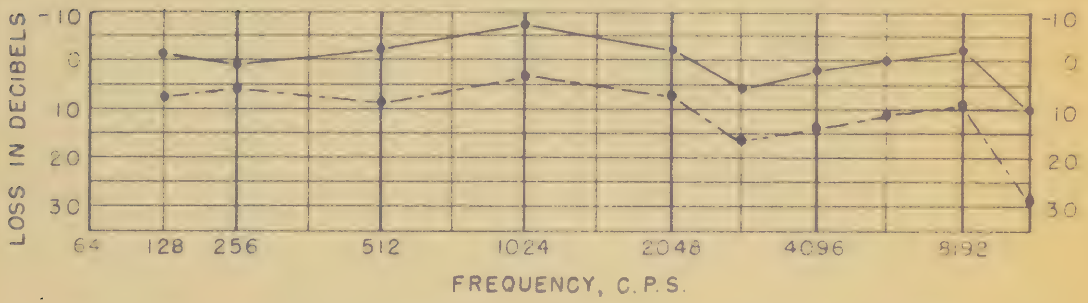

FIG. 3. AVERAGE AUDIOGRAMS OF 5 SUBJECTS BEFORE AND IMMEDIATELY AFTER 3 SEPARATE EXPOSURE PERIODS TO 3 SUCCESSIVE ROUNDS OF 90 MM GUN BLAST

LEGEND

AVERAGE NORMAL AUDIOGRAMS

WEARING PLASTIC EAR MOLDS WITHOUT ATTACHED HS-30

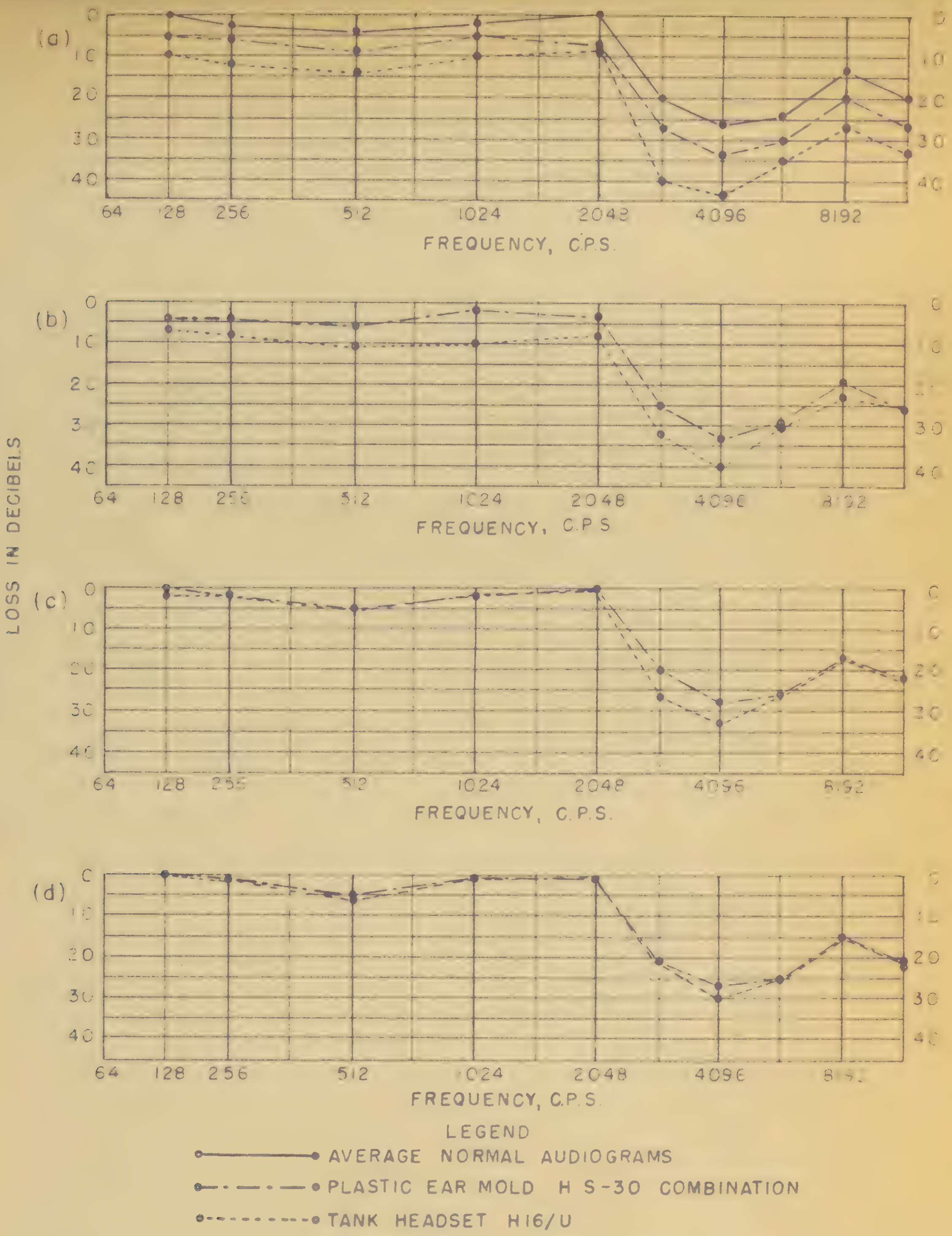

FIG. 4. AVERAGE AUDIOGRAMS OF 3 SUBJECTS BEFORE AND AFTER 2 SEPARATE EXPOSURES TO 2 HOURS OF FIELD RADIO COMMUNICATION

(a) IMMEDIATELY AFTER EXPOSURE
(b) 30 MIN. AFTER EXPOSURE
(c) 2 HRS. AFTER EXPOSURE
(d) 4 HRS. AFTER EXPOSURE

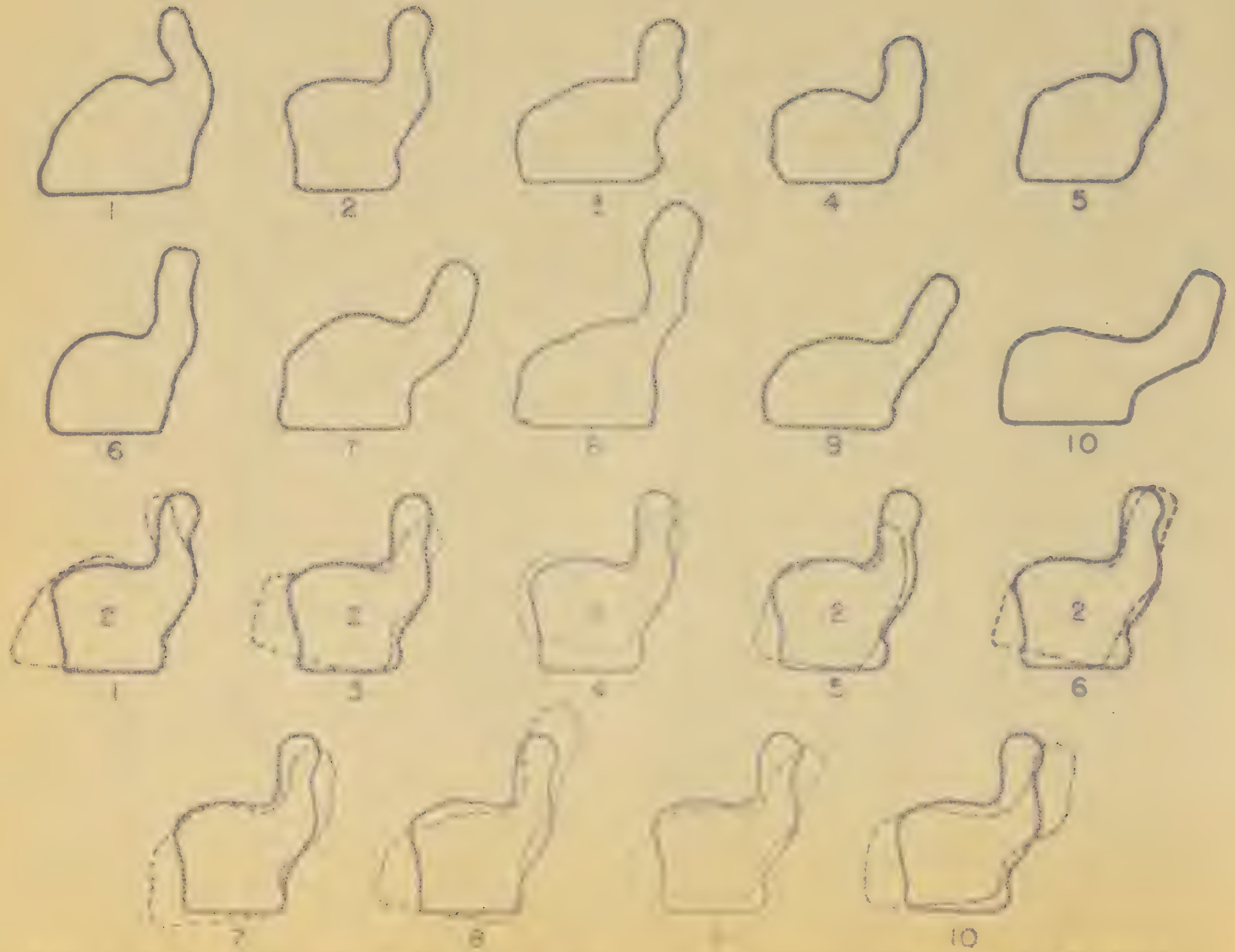

FIG. 8 ONE SIDE VIEW TRACING OF [illegible]TOGRAPH PICTURES
OF TEN REPRESENTATIVE SIZES AND SHAPES OF PLASTIC EAR MOLDS

Manual manipulation of the molds produced no evidence of damage after long continuous wear or after correct insertion and removal; however, slight soreness of the entire external ear occurred after incorrect insertion and removal.

No discomfort or auditory lesions from wearing plastic ear molds under the two extremes of environment were noted. One subject in the arctic climate preferred the plastic ear mold HS-30 combination over other standard headsets because of greater comfort, less bulk under the Parka Hood and better radio reception.

No satisfactory degree of fit, comfort or acoustic seal was obtained in the 10 subjects who had each received trial fittings of 10 different pairs of plastic ear molds. The reason for this is evident from examination of the shadowgraph tracings (2) in Figure 5 of a representative group of molds. The variations in size and contour of different molds represent anatomical variations of different ears. These anatomical differences are not easily deformable by the insertion of foreign molds without resultant discomfort or damage to the external ear.

III. SUMMARY AND CONCLUSIONS

Moderate physical blows to an inserted mold produced pain and erythema within the external auditory canal. Because of the rigid structure of the subject device, a more severe or heavier blow might possibly fracture the bony structure of the external auditory canal.

The plastic ear mold HS-30 receiver headset combination in which the mold canal is occluded afforded a partial protection against temporary hearing loss from concussion of gunfire but this protection disappeared when the ear mold was used without the attached HS-30 receiver headset in which the mold canal was patent.

Temporary hearing loss from field radio communication was less with the plastic ear mold HS-30 receiver headset combination than with the tank headset H16/U. A greater signal to noise ratio of field radio communication was noted with the plastic ear mold HS-30 receiver headset combination than with the tank headset H16/U because a lower volume control setting for adequate reception was required.

Moderate manual manipulation or use in extremes of environmental temperature produced no injury to the ear.

A satisfactory universal plastic ear mold was not obtained because of the variations in anatomical characteristics of the individual ear.

IV. RECOMMENDATIONS

The plastic ear mold is not recommended for general use, but may be suitable for individual use in specialized situations.

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EFFECTS OF THE COLD PRESSOR TEST ON GLOMERULAR FILTRATION AND EFFECTIVE RENAL PLASMA FLOW*

by

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Medical Department Field Research Laboratory
Fort Knox, Kentucky, 27 October 1947

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*Sub-project under Studies of Body Reactions and Requirements under Varied Environmental and Climatic Conditions. (MDFRL-55). Approved by CG, ASF, 31 May 1946.

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MEDEA

27 October 1947

ABSTRACT

EFFECTS OF THE COLD PRESSOR TEST ON GLOMERULAR FILTRATION AND EFFECTIVE RENAL PLASMA FLOW

OBJECT

Studies were made of the effects of the cold pressor test on renal function. Seven male volunteers who had no history of renal disease served as subjects. Glomerular filtration (as measured by mannitol clearance) and effective renal plasma flow (as measured by sodium para-aminohippurate clearance) were determined before, during and after immersion of the foot in ice water at 1°C. for 15 minutes.

RESULTS AND CONCLUSIONS

In 6 out of 7 subjects both glomerular filtration rate and effective renal plasma flow decreased either during the application of the cold stimulus or within approximately 30 minutes thereafter. In no subject did the effect persist longer. The average decreases in glomerular filtration rate and effective renal plasma flow, as compared with the control values, were 14% and 21%, respectively.

RECOMMENDATIONS

Further observations should be carried out, both in man and in animals, to clarify the mechanism by which local peripheral cold alters renal function.

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EFFECTS OF THE COLD PRESSOR TEST ON GLOMERULAR FILTRATION AND EFFECTIVE RENAL PLASMA FLOW

I. INTRODUCTION

The "cold pressor" test is a well-known method of determining the ability of the vasomotor system to respond to reproducible stimuli (1,2,3,4). Exposure of the hand or other body areas to ice water has been shown to cause pain, local vasoconstriction, and an elevation of arterial blood pressure (5,6). Recently, attention has been drawn to the effects of a local cold stimulus on renal function. Diminished urinary volume, increased specific gravity, decreased urea clearance values, and reduced minute chloride output have been observed following moderately prolonged exposure to the stimulus of the cold pressor test in pregnant and non-pregnant women (7). Equivocal observations of these phenomena have been reported on other subjects (8). It is the purpose of this paper to report the effects of local peripheral cold on the specific renal functions of glomerular filtration and effective renal plasma flow.

II. EXPERIMENTAL

A. Methods and Procedures

The subjects for these experiments were healthy white male volunteers between the ages of 18 and 37 years who, on physical examination and urinalysis, showed no evidence of renal disease. The men were asked to abstain from all solid food and liquids, with the exception of one glass of water at bed time, after supper on the evening prior to the experiment.

On the morning of the experiment the subject assumed a reclining position. An indwelling soft rubber catheter (5.5 mm. in diameter) was installed in the bladder. Following the application of a blood pressure cuff to the left arm, intravenous infusions of isotonic saline were started in the veins of each forearm at a rate of 1 ml./min. The needle in the left arm was used for drawing blood samples; that in the right, for the administration of test substances. While these procedures were being carried out (a period of about 1 hour), the subject ingested 1 liter of water. Then a priming dose of 40 ml. of a 25% mannitol solution and 3 ml. of a 20% sodium para-aminohippurate solution was administered intravenously within a period of 5 minutes. This was followed immediately by a sustaining infusion consisting of a mixture of 600 ml. of isotonic saline, 100 ml. of a 25% solution of mannitol and 16 ml. of a 20% solution of sodium para-aminohippurate at a rate of 4 ml./min. This rate was maintained throughout the experiment.

Zero time was established at 30 minutes after the beginning of the priming dose. Six or seven consecutive clearance periods, of approximately 15 minutes each, were carried out. After the first 2 or 3 of these periods, which served as controls, the subject's left foot was immersed to the level of the malleoli in stirred ice water at 1°C. and remained there throughout 1 entire period. Following removal of the foot from the cold, clearances were measured for 3 or 4 more periods.

Approximately 5 minutes after the beginning of each clearance period, blood samples were drawn through a three-way stopcock attached to the needle in the left arm, care being taken to rinse out the system several times, using withdrawn and reinjected blood in order to wash out any residual saline. Time was noted, to the nearest tenth of a minute, at the beginning and end of the drawing of each sample and the average taken as the blood sampling time. At the end of each period the bladder was washed with 20 ml. of saline and 20 ml. of air.

Auscultatory blood pressures were obtained at least twice during each of the control periods as well as within 30 seconds before and after immersion of the foot in the ice water. During the period of immersion and in the 2 following periods, determinations were made at approximately 2-minute intervals. Thereafter, the frequency of the readings was similar to that during the control periods.

Analyses for mannitol and sodium para-aminohippurate were carried out on heparinized plasma and on diluted urine samples according to the methods of Corcoran and Page (9) and Smith <u>et al</u>. (10), respectively. It has been suggested that the clearance of mannitol may be slightly lower than the true glomerular filtration rate (11). This would not alter the interpretation of these experiments since the importance of these data lies in their relative rather than in their absolute values.

B. <u>Results</u>

The results of these experiments are summarized in Table 1. A representative experiment is shown in Figure 1. As will be noted, in 6 out of 7 subjects both glomerular filtration rate and effective renal plasma flow decreased either during the application of the cold stimulus or within approximately 30 minutes thereafter. In no subject did the effect persist longer. The average decreases in glomerular filtration rate and effective renal plasma flow, as compared with the controls, were 14% and 21%, respectively. The observed depression of urine flow confirms the finding of Odell and Aragon (7).

In all subjects the blood pressure rose promptly after application of the cold stimulus and this rise was sustained throughout the period of immersion. Upon removal of the stimulus the blood pressure gradually decreased, returning to control levels in 15 to 20 minutes. Examination of these data reveals no correlation between the degree of blood pressure elevation and the observed changes in renal function.

III. <u>DISCUSSION</u>

The application of a peripheral cold stimulus is found to decrease urinary minute volume, glomerular filtration rate and effective renal plasma flow.

The large reduction of urine flow as compared with the moderate depression of glomerular filtration rate is regarded as evidence of alteration in the tubular reabsorption of water. This antidiuretic response may be of the same nature as that demonstrated by Rydin and Verney in dogs subjected to emotional stress (12).

TABLE 1

SUMMARY OF EXPERIMENTS

Subject		Date	Condition[1]	Number of Periods	Average Duration	Urine Flow	MANNITOL		PAH		Filtration Fraction[2]	Average Mean B.P.[3]	Change[4] of C_M[5]	Change[4] of C_{PAH}[6]	Change[4] of Av. Mean B.P.
No.	Initials						Plasma	Clearance	Plasma	Clearance					
					min	ml/min	mgm/ml	ml/min	mgm/ml	ml/min	r	mm Hg	%	%	%
1	P.M.S.	9-22-47	a	3	16.6	5.0	.635	164	.0360	711	.23	101			
	"	"	c	2	15.3	4.3	.671	150	.0325	542	.28	109	-9	-24	+8
	"	"	p	2	14.9	4.8	.687	188	.0252	864	.22	103	+15	+22	+2
2	E.A.M.	9-23-47	a	3	16.8	13.2	.725	152	.0280	822	.19	95			
	"	"	c	2	14.9	4.2	.801	133	.0292	562	.27	107	-12	-32	+13
	"	"	p	2	15.5	4.9	.821	147	.0251	843	.18	95	-3	+3	0
3	A.J.M.	9-24-47	a	2	15.9	13.1	.463	189	.0233	637	.30	116			
	"	"	c	3	14.5	8.7	.495	192	.0190	663	.29	133	+2	+4	+15
	"	"	p	2	15.1	9.4	.641	164	.0188	663	.25	120	-13	+4	+4
4	R.P.S.	9-25-47	a	2	15.0	16.8	.513	182	.0165	696	.26	104			
	"	"	c	2	15.0	6.4	.519	132	.0141	508	.26	117	-28	-27	+13
	"	"	p	2	14.8	6.9	.546	154	.0178	645	.24	106	-15	-7	+2
5	F.A.M.	9-29-47	a	2	15.0	23.3	.744	153	.0193	926	.17	106			
	"	"	c	1	15.3	15.3	.770	118	.0180	711	.17	124	-23	-23	+17
	"	"	c	2	14.8	5.4	.936	117	.0192	737	.16	124	-23	-23	+17
	"	"	p	2	12.5	5.7	.972	128	.0170	862	.15	115	-16	-7	+8
6	F.H.M.	9-30-47	a	2	14.8	12.2	.502	179	.0150	891	.20	90			
	"	"	c	2	15.1	5.2	.590	154	.0175	566	.27	108	-14	-26	+20
	"	"	p	2	15.3	5.7	.680	191	.0160	790	.25	89	+7	+7	-1
7	D.R.F.	10-6-47	a	2	15.9	11.3	.791	116	.0244	627	.19	95			
	"	"	c	3	15.2	2.7	.810	102	.0256	486	.21	106	-12	-22	+12
	"	"	p	2	16.0	3.1	.971	114	.0266	655	.17	98	-2	+5	+3
Average % of Control			c										-14	-21	+14
" " " "			p										-4	+4	+3

1. a - Control Periods
   c - Periods of Cold Effect
   p - Recovery Periods

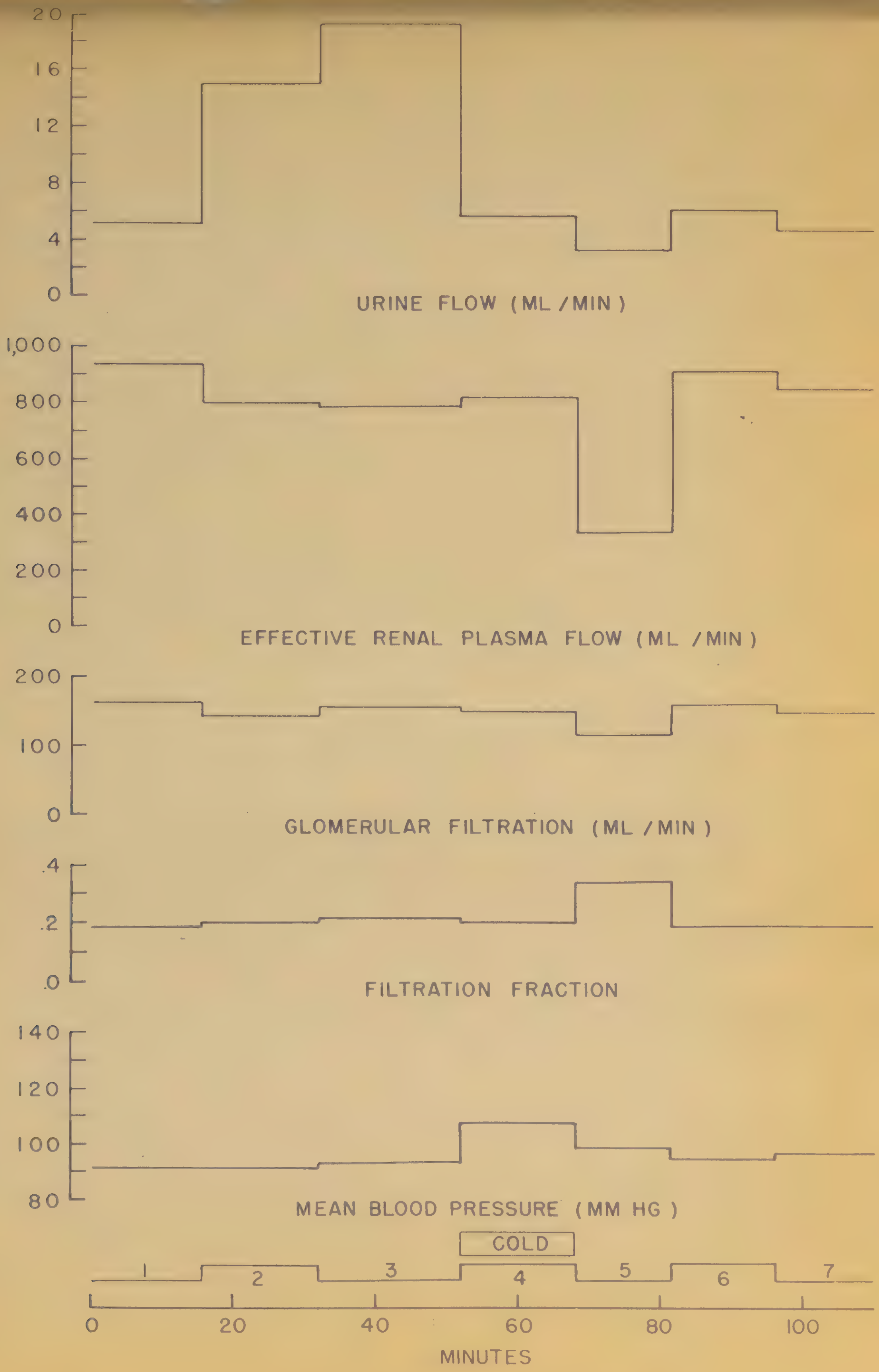
2. Filtration fraction = $\frac{\text{Mannitol Clearance}}{\text{PAH Clearance}}$

3. (Systolic + diastolic) ÷ 2 = Mean B.P. Average of all readings.

4. Change from Control (a) Average.

5. C_M = Mannitol Clearance

6. C_{PAH} = Para-aminohippurate Clearance Change from Control (a) Average.



URINE FLOW (ML / MIN)

EFFECTIVE RENAL PLASMA FLOW (ML / MIN)

GLOMERULAR FILTRATION (ML / MIN)

FILTRATION FRACTION

MEAN BLOOD PRESSURE (MM HG)

FIG. I REPRESENTATIVE EXPERIMENT

(E.A.M.)

The results obtained on subject No. 3 (A.J.M.--26 years) may be of interest. While the blood pressure rose in all experiments as a result of the stimulus, this was not associated with changes in glomerular filtration and renal plasma flow in this one subject. The initial diastolic blood pressure (128/90) together with the blood pressure response (164/116), during exposure to cold, would suggest according to the criteria of Hines and Brown (13) that this individual belongs to the prehypertensive group. However, as indicated above, these observations do not establish a correlation between the degree of blood pressure rise and the changes in renal function in response to the cold stimulus.

The mechanisms ultimately responsible for these findings remain to be identified and are being investigated.

IV. CONCLUSIONS

Evidence is presented that, in 6 out of 7 subjects, cold applied to the foot caused a decrease in glomerular filtration rate and in effective renal plasma flow.

V. RECOMMENDATIONS

Further observations should be carried out both in man and in animals to clarify the mechanism by which local peripheral cold alters renal function.

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ACCLIMATIZATION TO EXTREME COLD

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ACCLIMATIZATION TO EXTREME COLD

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The only unequivocal evidences of acclimatization to environmental conditions differing radically from normal temperate environments are those reported to occur in hot environments (4, 5, 12, 14). Data on the process of acclimatization to cold are lacking, although Bazett and his co-workers (1, 2, 16) have demonstrated slow adaptations to cool environments. A most remarkable example of adaptation to an ambient of approximately 0°C. has been shown to occur in the Australian aboriginal (6). Not only does he exhibit a greater lability toward vasoconstriction but also his heat production on exposure to cold remains at a constant level. On the other hand, according to Hill and Campbell (7), children receiving cold open-air treatment have elevated basal metabolic rates. Eskimos also exhibit BMR's from 14 to 21 per cent above normal standards (3). Animals have increased metabolic rates during and immediately after a period of continuous exposure to cold (11, 13, 15).

Most of these observations were made at relatively warm environments, freezing and above, and consequently do not provide the answer as to whether acclimatization occurs in the very extreme ambient temperatures observed in arctic and sub-arctic regions. Arctic explorers differ widely in their opinions both as to the occurrence and the rate of development of acclimatization.

In previous reports, Horvath and co-workers (9, 10) discussed the effects of short intermittent exposures to environments as low as -47°C. on the functioning of the heat regulating apparatus of men who either sat quietly or worked at a standard rate. Due to the nature of the observations, it was not possible to obtain evidence for or against the development of acclimatization to low temperatures. The data to be presented in this paper are concerned primarily with the reactions of men to an eight day period of continuous exposure to an ambient temperature of -29°C.

METHODS. A group of ten healthy young soldiers[4] were trained for twelve days outdoors in the July heat of Fort Knox, Kentucky. Their training consisted of walking a distance of 12 miles daily at a speed of 3.0 mph. Additional walks on the treadmill were also made daily. After this preliminary period, they were brought into the cold chamber described in another report (9) and remained there for three days in an envirionment of 25°C., R. H. 50 per cent. The chamber was then cooled to -29°C. Six of the ten men remained in

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[4] Average age, 21.5 years; height, 68 inches; weight, 155 pounds; and surface area, 1.83 square meters.

the cold room continuously day and night for eight days, while the remaining four slept in their barracks at night, but entered the cold chamber before breakfast each morning and remained there until after sundown each evening. They engaged in practically the same activities as the six men who resided continuously at −29°C. In the cold room the men wore the six piece Arctic Suit[5] M-1942, which has an insulative value of 3 to 4 Clo. Their daily activities for the three days previous to cooling the chamber, for the eight days at −29°C., and for the three days following the cessation of their low temperature exposure consisted of this set pattern: One hour's walk at 3.0 mph. after breakfast, then two hours of quiet sitting followed by lunch; after lunch, an hour's walk, a half hour's heavy work period, another hour's walk, a period of quiet sitting for 40 minutes, a series of psychological tests, and then dinner. There was some entertainment in the form of radio and reading during the day and motion pictures in the evening. Partial escape from the cold was permitted in the evening by the provision of a small hut in the cold chamber (temperature −5 to 0°C.). However, the men usually retired into their sleeping bags early in the evening.

TABLE 1

SUBJECT	AGE	HEIGHT	WEIGHT	SURFACE AREA (M^2)
		cm.	*kg.*	
FO	19	182	76.6	1.98
CU	20	175	70.6	1.85
RE	20	172	65.8	1.76
MO	19	165	56.6	1.64
BE	27	178	68.7	2.00

The results of studies on fluid balance, blood, and psychological responses (8) will be reported in later publications. The present paper is based primarily on observations of the sitting and working metabolism of five of the ten subjects. Only one of these five men was a member of the group which spent a portion of its time outside the cold room. The physical characteristics of these subjects are given in table 1. The procedures employed in this investigation were similar to those previously described (9, 10). The sitting metabolism of subject BE was obtained with a closed circuit apparatus and consequently for two hours he breathed air which was at a temperature of +20°C. For all the other sitting subjects the temperature of the inspired air was −29°C., the expired air being collected for ten minutes in Douglas bags. Analyses of aliquots of the collected air were made in duplicate on Haldane machines. Skin temperature data were incomplete, since the correct techniques for preventing breakage of the copper

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[5] This consisted of two sets of $\frac{3}{8}$ inch pile trousers, two sets of $\frac{3}{8}$ inch pile parkas and a white cotton camouflaged outer suit. The inner pile suit was worn with pile towards the skin, while the pile of the outer suit faced the camouflaged garment. Two pairs of heavy wool socks were worn inside mukluks. Hand protection was provided by a pair of wool gloves and outer shell mittens (M-1943).

constantan thermocouples had not been fully developed. However, some data on toe temperatures were adequate and will be discussed. Rectal temperatures were obtained by means of calibrated clinical thermometers.

Results and discussion. The average rectal temperature of the five subjects throughout the day (measurements made on arising, after first work period, after rest period, after each of three afternoon work periods, and prior to retirement) was approximately 37.8°C. during the entire eight days at low environmental conditions. This was very similar to values obtained during the preliminary and the post-exposure periods. No significant changes were noted in the basal rectal temperatures secured while the subjects were still in their sleeping bags. Variations were noted in each subject but were not consistent. Basal values as low as 35.2°C. were found in a number of cases. The rate of fall of rectal temperatures during the sitting periods did not differ appreciably on any of the eight days. During the last third of the sitting period of the third day, there was observed a large fall in the rectal temperatures of all subjects, but its cause was not determined. Since adequate consecutive data on mean skin temperature were not obtained, changes in mean body temperature could not be estimated. In the few subjects on whom chest and thigh temperatures were successfully secured on all days at the low ambient temperatures, no changes attributable to duration of exposure were found.

The basal heart rate was not altered during the period of cold exposure. The mean values on the second day of cold were 56, on the fifth day, 55, and on the eighth day, 58. The heart rates during the sitting periods (table 2) were variable and might be explained as due to increased muscle tone or slight shivering by some of the subjects.

The mean oxygen consumption (open circuit method), during the two hours that four subjects sat quietly (fig. 1), showed an increase of approximately 30 per cent over control values at +25°C. Detailed data secured at three points during each two hour sitting period are given in table 1. No consistent pattern was exhibited during the eight days of exposure. While in general all subjects showed a trend to remain at an elevated level during the exposure to cold, two roughly similar groupings were noted in the daily variations of caloric expenditure. Nothing in the past experiences or the physical characteristics of the subjects could be correlated with these patterns.

After returning to a comfortable environment, the subjects' oxygen consumption decreased but was still higher than the pre-cold control values. This stimulating effect of cold exposure confirmed the results of animal experiments conducted by Horvath et al. (12).

It is of interest to compare the metabolic rates obtained on two subjects similarly exposed (fig. 2) when one of them, BE, breathed warm air while the other, FO, breathed cold air (−29°C.). Neither of these two subjects reported gross shivering, although they undoubtedly had some increased muscular tone. The increased metabolism was seen initially in both subjects, but after the first three days BE's heat production began to decrease, and in the last few days it was only slightly elevated. This response would be considered a classic example

of acclimatization to cold except that it was not noted for any of the four subjects who were breathing cold air. The after-stimulating effect of cold on metabolism was not observed to occur in subject BE. It is of special note that, while all the subjects reported they did not mind the cold so much after the first few days, only BE stated that he was definitely more comfortable. Whether he was the only subject to be acclimated or whether the breathing of warm air was the deciding factor was not then determined. Some experiments performed later failed to demonstrate any beneficial effects of breathing warm air during short periodic exposures to low environmental temperatures.

TABLE 2

The mean metabolic values obtained on four subjects who sat for a period of two hours each day during continuous exposure to the designated environmental temperatures

	ENVIRONMENTAL TEMP. °C										
	25.0°C.	−29.0°C.							25.0°C.		
		Days of exposure									
		1	2	3	4	5	6	8	9	10	11
					At 40 minutes						
R.Q.	0.86	0.83	0.86	0.86	0.83	0.75	0.85	0.88	0.82	0.79	0.83
Ventilation L./min.	8.2	10.5	9.9	9.6	9.4	11.0	10.3	10.7	9.2	8.3	8.3
Oxy. cons. ml./min.	354	482	472	451	427	493	461	501	378	368	378
Cal./hr.	173	233	230	220	206	236	224	245	183	176	183
Rectal temp. °C.	37.2	37.0	37.3	37.4		36.7	37.0	36.5	36.6	36.7	36.9
Heart rate/min.	60	62	68	74	74	78	66	69	81	75	74
					At 80 minutes						
R.Q.	0.89	0.88	0.82	1.04	0.86	0.90	0.86	0.85	0.94	0.92	0.80
Ventilation L./min.	7.5	8.5	8.0	8.4	9.0	12.0	9.4	9.8	9.5	9.9	8.2
Oxy. cons. ml./min.	307	358	368	316	381	503	374	416	303	309	324
Cal./hr.	150	175	178	161	186	247	182	202	151	153	156
Rectal temp. °C.	36.7	37.1	37.2	37.1	36.9	37.1	36.9	36.6	36.9	36.8	37.0
Heart rate/min.	74	72	78	72	78	80	63	70	81	70	78
					At 120 minutes						
R.Q.	0.88	0.82	0.81	0.88	0.85	0.86	0.83	0.92	0.82	0.80	0.82
Ventilation L./min.	7.4	9.4	9.2	9.5	9.7	10.2	9.4	9.6	8.5	7.9	7.8
Oxy. cons. ml./min.	300	400	426	419	442	455	424	420	354	330	332
Cal./hr.	136	193	204	210	215	222	205	208	171	158	160
Rectal temp. °C.	36.9	36.9	36.9	36.3	36.8	36.9	36.8	36.7	36.9	36.6	36.9
Heart rate/min.	66	64	61	65	59	75	72	73	74	76	70

The toe temperatures obtained on BE and FO are of considerable interest (figs. 3a and 3b). They show the changes that occurred during the three hour morning periods (8 to 11 o'clock). Their toe temperatures were quite low from awakening through breakfast, but the walk raised them to fairly high levels. During the subsequent two hours of cooling, seated subject FO (fig. 3b) exhibited a strikingly similar pattern on all days, his final temperatures reaching the neighborhood of 10°C., similar to his pre-exercise levels. On the other hand, BE's toe temperatures presented definite evidence of an acclimatization effect

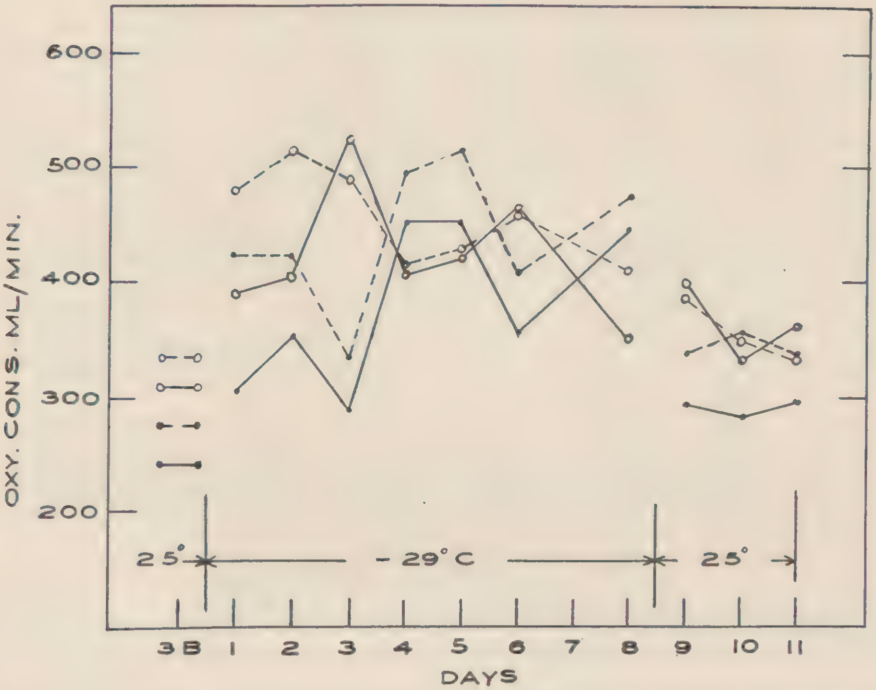

Fig. 1. The average oxygen consumption of four seated subjects during a two hour period in comfortable and cold environments.

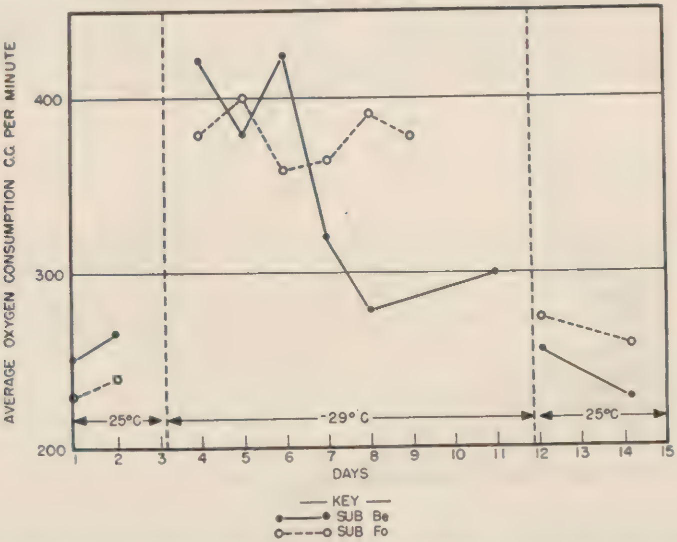

Fig. 2. Average oxygen consumption of two subjects sitting for two hour periods while residing continuously at the designated ambient temperatures.

in that the extremities not only warmed up more rapidly and to a greater degree on the last days of cold exposure, but also cooled at a definitely slower rate.

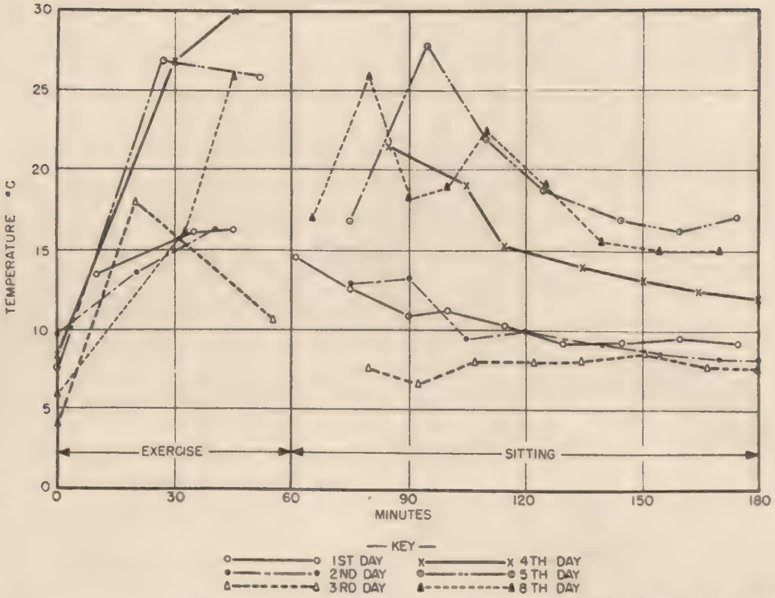

Fig. 3a. Toe temperatures of subject BE (one of the two subjects of fig. 2) during the morning hours of a period of continuous residence at a low environmental temperature.

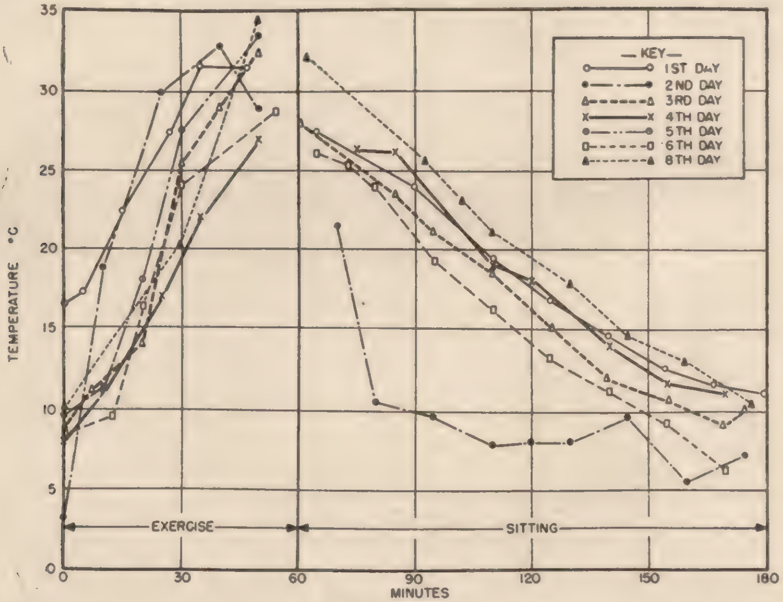

Fig. 3b. Toe temperatures of subject FO (one of the two subjects of fig. 2) during the morning hours of a period of continuous residence at a low environmental temperature.

There was a positive correlation between the higher final toe temperature and the mean caloric production during this cooling-off period. When his extremities

were cold, his metabolic rate was elevated and vice versa. If BE had been our only subject, definite evidence of acclimatization, in the usual interpretation of the word, again would be said to have occurred. However, his response was atypical in view of the reactions of the other subjects, and the breathing of warmer air may have altered his responses to some extent.

Metabolic observations were made on four subjects performing a standard amount of work at 25° and −29°C. Unfortunately, a follow-up period at 25°C. was not possible due to our having only one treadmill. Average data on four subjects are presented in table 3, with a graphic presentation in figure 4 of the findings on subject CU. As previously reported (10), exposure to low environmental temperatures was accompanied by an increased energy expenditure for the performance of a standard amount of work. The 25 per cent average rise in caloric output was slightly, but not significantly, higher in this group of subjects than in the group exposed for only a single hour to a similar ambient temperature (10). The energy expenditure during work decreased with continued exposure to the low ambient temperature. Although no regular pattern was evident in this increased efficiency of performance, viz., a return to cool environmental levels, the values obtained on the last two days were the lowest ones observed in the cold. Thus, continued exposure appeared to have a definite effect on physiological functions in that stimulation due to cold was less evident toward the end of exposure. This effect was not noted in all of the subjects (fig. 4). Except for his second day at −29°C., CU showed only minor changes in caloric output, which was partially a reflection of the slight rise in R.Q. observed in this subject.

TABLE 3

Metabolic observations on four (4) men, dressed in Arctic clothing and walking on a treadmill at 3.0 MPH and a 3.3 per cent grade while exposed to an environmental temperature of −29.0°C. continuously for eight (8) days

ENVIRONMENTAL TEMPERATURE	VENTILATION		RESPIRATORY QUOTIENT		OXYGEN CONSUMPTION		HEAT PRODUCTION	
	L./min	Δ%		Δ%	L./min	Δ%	Cal/hr	Δ%
+25.0°C.	26.7		0.92		1.22		360	
Days at −29.0°C.								
First	33.2	24.3	0.86	−6.5	1.65	35.2	483	34.2
Second	31.1	16.5	0.87	−5.4	1.50	23.0	440	22.2
Third	30.9	15.7	0.88	−4.4	1.54	26.2	452	25.6
Fourth	32.4	21.3	0.90	−2.2	1.51	23.8	448	24.4
Fifth	32.6	22.1	0.86	−6.5	1.59	30.3	464	28.9
Sixth	31.3	17.2	0.89	−3.3	1.46	19.7	430	19.4
Eighth	29.8	11.6	0.86	−6.5	1.50	23.0	438	21.7
Average*........	31.6	18.4	0.87	−5.0	1.54	25.9	451	25.2

* For days at −29.0°C.

The average oxygen consumption of the four subjects appeared to have reached

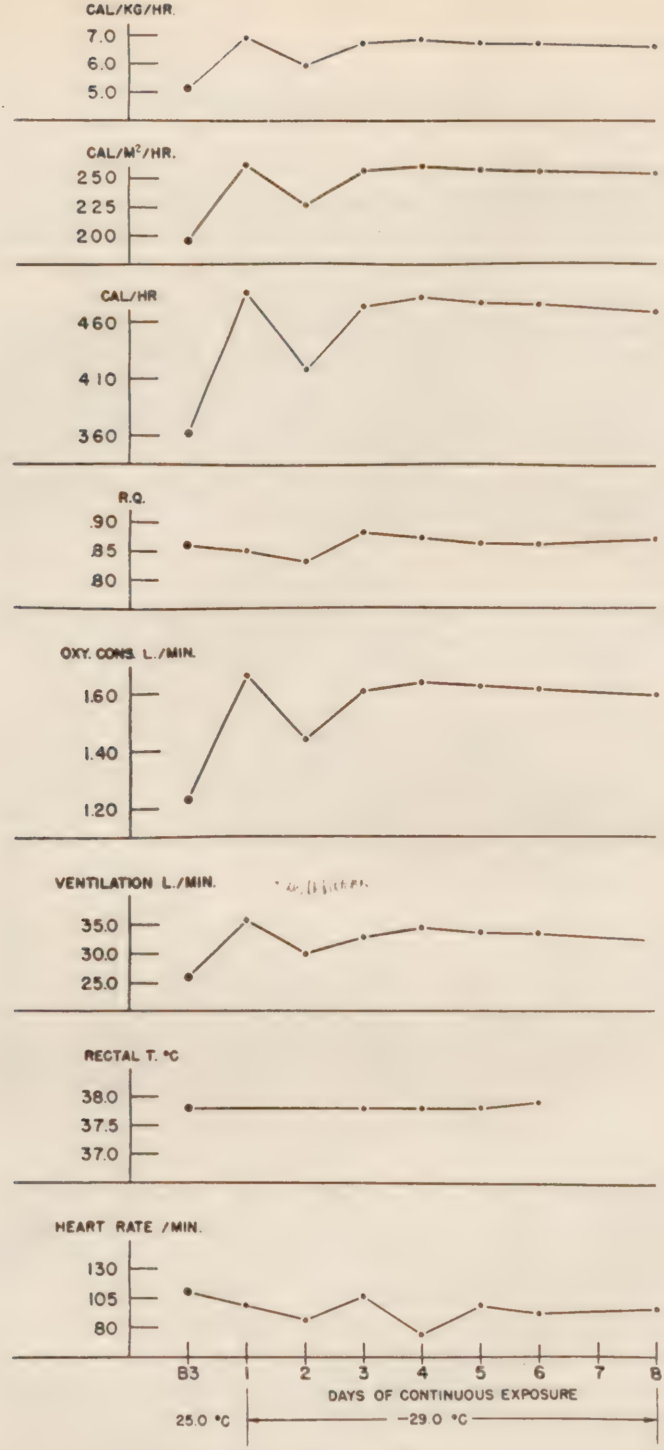

Fig. 4. Observations made on subject CU during a one hour walk (a.m.) on a treadmill at a speed of 3.0 mph and a 3.3 per cent grade before and during an eight day period of continuous residence in an environment of −29°C.

a fairly steady level after the first day in the low ambient temperature, the greatest variations being observed on the fifth and sixth days. The fall in R.Q. from the control days averaged about 5 per cent and showed minor variations during the succeeding days in the cold. The maximal fall occurred on the first day and, although it varied from day to day in the cold, it did not approach the pre-cold day values. Subject CU (fig. 4) again differed from the other subjects in that his R.Q. figures were generally higher during cold exposure than in the comfortable environment.

The ventilation rates at all times were greater at −29°C. than at 25°C. This increase, an average of 18.4 per cent, was accomplished through increased depth of breathing, as the respiratory rate was not affected. The smallest increase, approximately 12 per cent, was observed on the last day of the test. The greatest change was noted on the first day in the cold. Lower values, but not in a definite progression, were found on all succeeding days.

As illustrated in figure 4, the rectal temperature at the completion of the work period remained relatively constant during the successive days of cool and cold exposure. It is unfortunate that the constant breakage of thermocouples prevented collection of adequate data on the changes in body surface temperatures. The thigh temperatures obtained appeared to be higher on the last days than on the first days of cold exposure. The heart rate slowly decreased, the average fall being 12 beats. This may be in part a reflection of training.

Although the cost to the individual to do a given amount of work in the cold was always greater, a slight diminishing of this greater energy expenditure appeared to occur with longer periods of consecutive exposure to the low ambient temperature. This was reflected primarily in reduction of the total caloric output and the lowering of the minute ventilation volume.

Only one of the quietly sitting subjects exhibited measurable improvement in his ability to tolerate cold. All of the other men had variable responses and none of the changes in the physiological measurements could be attributed directly to length of exposure. It is possible that the duration of exposure was too short and that changes similar to those seen in subject BE may have occurred if the exposure to the cold had been continued.

There are indications that men do become acclimated to cold and that certain physiological mechanisms are involved in this process. Unfortunately, the individual variations are so great that no clearly delineated statement of the mechanism can be given at this time.

SUMMARY

Metabolic observations were made on five subjects who resided continuously for three days in a comfortable environment, 25°C., for eight days in a cold environment, −29°C., and for another three day period at 25°C. No changes in basal values for heart rate or rectal temperature occurred. The caloric expenditures during quiet sitting and while performing a standard amount of work were higher during exposure to the low ambient temperature. The duration of exposure to low temperatures did not markedly influence the energy output during the sitting period for four of the five subjects. The fifth individual, who

was breathing air of approximately 20°C. during this time, showed a striking decrease in caloric output with increased exposure. The significance of this finding and its association with a higher level of toe temperature has been discussed. Four of the subjects exhibited an increased metabolic rate—an afterstimulating effect of cold—on their return to the control environment. This was not observed in the fifth subject, the individual mentioned above.

The energy requirements of the standard work on a treadmill at 3.0 mph and a 3.3 per cent grade were increased during low temperature exposure. A small but definite return towards normal values occurred with continued exposure, but its relation to the development of a state of acclimatization was not clear. The decrease could be explained adequately on the participation of a number of other factors.

There is some indication from the data accumulated in this study that acclimatization to cold may occur, but at the present the evidence is too equivocal for a definite statement.

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POST-EXERTIONAL ORTHOSTATIC HYPOTENSION

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Transitory non-fatal collapse following severe physical effort is a familiar phenomenon in competitive sport. Jokl[7] has described the clinical picture of this "Sportkrankheit" and Mateef and Petroff[8] and Mateef[9] first described and studied the orthostatic hypotension which is one of its circulatory aspects. Brogdon and Hellebrandt,[2] Eichna and Bean,[3] Mayerson,[10] Allen, Taylor and Hall[1] have confirmed the occurrence of orthostatic hypotension following hard muscular work. However, observations dealing with the nature of this postural hypotension are still few. While studying the physiologic effects induced in healthy young men worked to the limits of their physical tolerance, we encountered post-exertional orthostatic hypotension and had an opportunity to study it. Some of these studies are here presented.

Subjects and Methods. The subjects were all young, healthy soldiers (enlisted men) undergoing some phase of military training beyond basic training. They were, therefore, physically more fit than the usual normal group drawn from civilian life. The required work was performed at all hours of the day, except immediately after meals, and consisted of exercise tests designed to determine physical fitness. Two of the tests, the pack test and the treadmill test, were of the acute, exhausting type; the third, the hike, was of the long, enduring type. In the pack test,[5] the subjects stripped to shorts, socks and shoes, and carrying a pack weighing one-third of their body weight, stepped up and down on a platform 16 inches high, once every 2 seconds for 5 minutes, unless exhaustion forced them to discontinue before that time. In the treadmill test,[6] the subjects, similarly clothed but without pack, ran on a motor-driven treadmill for 5 minutes, unless forced by exhaustion to discontinue before that time. The speed of the treadmill was 7.5 miles per hour for the initial tests and 5.6 miles per hour for the repeat tests; in all tests the treadmill grade was 8.6%. The physical effort of these 2 tests is such that approximately one-third to one-half of the healthy young men attempting them fail to complete the required 5 minutes of work. In the hike, the men wore regulation fatigue uniforms of herringbone twill, carried packs weighing 20 pounds and were required to walk 32 miles in the best time they could, usually 7 to 9 hours. The pack and treadmill tests were performed indoors at an ambient temperature of about

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74° F. The hike tests were performed on the open road in the moderately warm weather of late spring. On completing the pack and treadmill tests, the men sat down for 5 minutes before postural studies were begun. In the hike tests these studies were started immediately after finishing the march.

Except after several of the hikes, when men changed from the lying to erect (90 degree) position by their own effort, position was always changed passively by means of a tilt table. The erect position was 70 degrees erect with the weight supported by the legs. No attempt was made to diminish postural sway or movement, other than repeated admonitions to stand still. Position was changed alternately from erect (70 degrees) to flat and flat to erect (70 degrees) at 5 minute intervals, except when syncope shortened the time in the erect position. While in each position the heart rate (by palpation or auscultation) and blood pressure (by auscultation, using a mercury manometer) were simultaneously and repeatedly determined, usually at 30 to 60 second intervals. At least one set of determinations in the flat and erect (70 degree) positions preceded an exercise test. Following exercise, all subjects were observed through at least 2 erect periods, separated by 1 in the supine, and thereafter through as many changes of position as the individual case required. In certain instances respiratory rates, vital capacities, and electrocardiograms were taken in each position before and after exercise.

In a number of subjects the relationship between their postural responses after exercise and their cardiovascular lability was studied by determining the changes in heart rate and blood pressure induced by several stimuli administered in the control period: (*a*) posture test, change from supine to erect (70 degrees); (*b*) cold pressor test, immersing one forearm in ice water for 2 minutes; (*c*) mental pressor test, requiring the subject to do arithmetical problems (multiply 3 digits by 2 digits) in his head for 5 minutes; (*d*) exercise test, changes during the 5 minutes immediately on completion of standard exercise.

Results. The post-exertional orthostatic responses are divided into 3 groups: syncopal, abnormal and normal. The *syncopal* group includes those subjects who developed syncope and were unable to remain erect for 5 minutes during either one or both of the 2 required erect periods after exercise. While erect, their blood pressures were usually very low and their heart rates rapid but collapse rather than any level of blood pressure or heart rate was the criterion for inclusion in this category. When upright, these subjects developed the typical symptoms and signs of syncope, either singly or in varying combinations, and in varying intensity. Almost invariably present were marked fatigue, drowsiness, apprehensiveness, increasing discomfort, nausea, abdominal cramps, lightheadedness and dizziness, and the sensation of impending collapse. In the more severe instances, dimness of vision progressing to tubular vision and "blackout," vomiting, disorientation, inability to move or obey commands even though hearing them progressed to complete loss of consciousness and crumpling at the knees, at which time the men were tilted flat. These symptoms were accompanied by various signs, yawning, deep breathing, increasing pallor leading to a pallid ashen cyanosis, profuse sweating, gasping respiration, apprehensive restlessness or listlessness, a steadily falling blood pressure with very narrow pulse pressure, markedly decreased intensity of heart sounds, and a rapid, weak pulse. Just before consciousness was lost, and the subject tilted supine, the heart in a number of subjects slowed markedly. Once supine, all symptoms quickly improved or disappeared completely. For a short time immediately after becoming supine, a marked bradycardia and elevation of blood pressure were often encountered, but as the supine position was maintained both heart rate and blood pressure returned to normal.

The *abnormal* group includes those subjects who were able to remain erect for the required 5 minutes during both of the post-exertional erect periods, but who, during at least 1 of them, sustained a fall in systolic blood pressure to abnormally

low levels, here defined as 100 mm. Hg or less, provided that that level was at least 10 mm. Hg lower than the lowest pre-exercise, erect, systolic blood pressure. Many men developed symptoms and signs similar to those in the syncopal group. Usually they were more mild but in some instances they were so severe that the men were just able to remain erect for the required 5 minutes. If the erect period had been further prolonged some men would surely have fainted. Others had no symptoms though severely hypotensive.

The *normal* group includes all of the others, men who remained erect after exercise without symptoms and with systolic blood pressures above 100 mm. Hg.

TABLE 1.—BLOOD PRESSURE, HEART RATE AND DURATION OF ERECT POSTURE AFTER ACUTE EXHAUSTING WORK

(The data for each group are averages of the final readings taken before position of subject was changed)

		First erect period					Supine period (5 min.)				Second erect period				
			Blood pressure (mm. Hg)				Blood pressure (mm. Hg)					Blood pressure (mm. Hg)			
Group	No. subjects	Duration (min.)	Syst.	Diast.	Pulse	Heart rate (per min.)	Syst.	Diast.	Pulse	Heart rate (per min.)	Duration (min.)	Syst.	Diast.	Pulse	Heart rate (per min.)
Normal	14	5.0	119	88	31	115	117	73	44	100	5.0	114	90	24	112
Abnormal . . .	10	5.0	103	76	27	116	117	67	50	105	5.0	95	83	12	116
Syncopal . . .	9	2.4	*98	*72	*26	°122	118	68	50	108	2.6	‡81	†64	†17	118

* Average of the 4 subjects with obtainable blood pressure; blood pressure unobtainable in 5 subjects.
† Average of the 5 subjects with obtainable blood pressure; blood pressure unobtainable in 4 subjects.
‡ Average of the 6 subjects with obtainable blood pressure; blood pressure unobtainable in 3 subjects.
° Average of 8 subjects; pulse missing on 1 subject.

ORTHOSTATIC HYPOTENSION FOLLOWING ACUTE EXHAUSTING PHYSICAL WORK. Since the pack test and treadmill test both required essentially the same type of physical effort and produced very similar findings, the results of these 2 tests are combined into one analysis.

Type of Response and Incidence. Of 33 men subjected to acute exhausting physical work approximately one-half (19 or 57.6%) developed post-exertional orthostatic hypotension, with 9 (27.3%) in the syncopal group and 10 (30.3%) in the abnormal group (Table 1). Thus, every other man developed post-exertional orthostatic hypotension and 1 man in 4 had syncope. Table 1 indicates the progressive fall in blood pressure from the normal through the abnormal to the syncopal group, and for the same group order an increasing, but less striking, rise in heart rate. Syncope was most closely related to the systolic blood pressure and was most likely to occur when it fell to about 80 mm. Hg. Pulse pressure bore less relationship to syncope: the pulse pressure for the abnormal group was as low, and even lower, than that for the syncopal group (second erect period, Table 1). Circulatory failure in the erect position was more marked, as a rule, in the second erect period, 15 to 20 minutes after the cessation of exercise, than in the first erect period, 5 to 10 minutes after work. This is indicated by the greater number of syncopes and the greater fall in blood pressure in the second erect period than in the first (Table 1). The similarity in blood pressures for all 3 groups when the subjects were supine indicates that the circulatory disturbance is apparent only in the erect position.

Chart 1 indicates the response of a man in the normal group. Charts 2 and 3 are typical of 2 types of syncopal responses. In Chart 2 the hypotension and syncope develop "immediately," in the first erect period, but nevertheless, become more severe in subsequent upright periods. In Chart 3 the onset of hypotension and syncope are "delayed." The first erect period is tolerated without difficulty and with sustained blood pressures and heart rates. Hypotension and syncope develop in this second erect period and remain

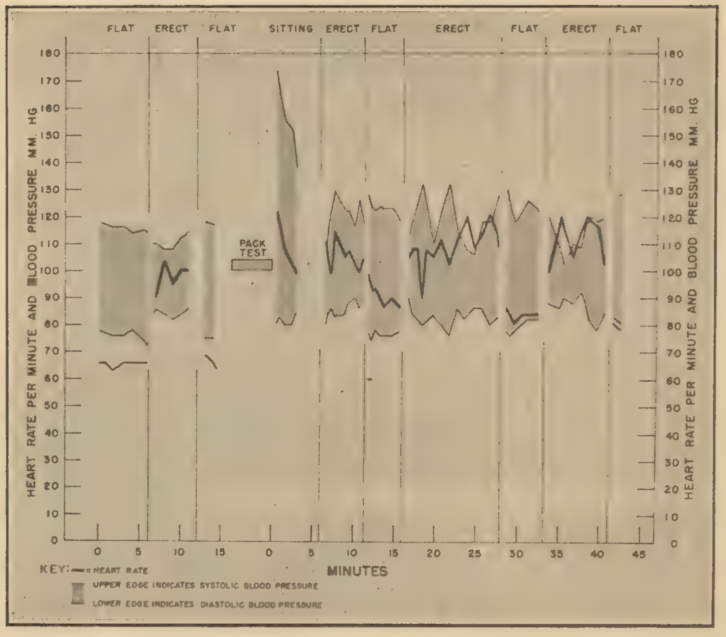

CHART 1.—Normal blood pressure in the erect posture following acute exhausting exercise. In this and subsequent charts the heavy black line indicates the heart rate; the upper level of the shaded area the systolic blood pressure; the lower level of the shaded area the diastolic blood pressure.

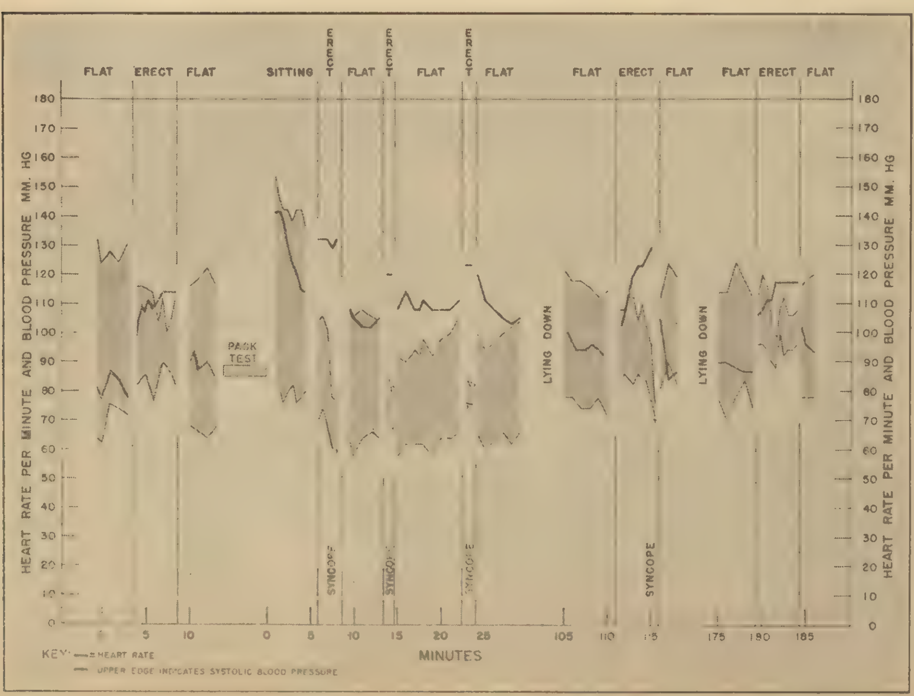

CHART 2.—Orthostatic hypotension with syncope following acute exhausting exercise. The hypotension and syncope develop during the first erect period after exercise and are still present 2 hours after cessation of effort.

severe thereafter. Usually tachycardia accompanies the hypotension (Chart 2) but at times the heart slows just as collapse is about to occur (Chart 3). In 1 instance (Chart 3 at point X) such a cardiac slowing progressed to an asystole of 19 seconds, with collapse of the subject.[4]

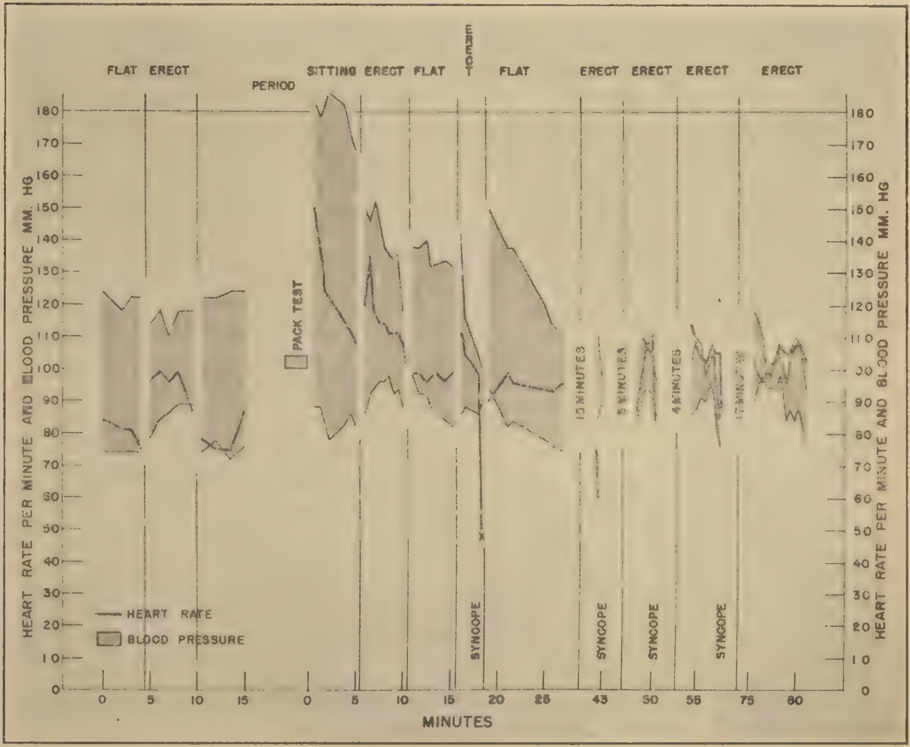

Chart 3.—Orthostatic hypotension with syncope following acute exhausting exercise. The hypotension and syncope are delayed in appearance and do not develop until the second erect period, following a first erect period which was tolerated without difficulty. Terminal bradycardia accompanied the hypotensive episodes.

Duration. The duration of the post-exertional orthostatic hypotension varies but it tends to persist for an unexpectedly long time. Thus in 1 subject (Chart 3) orthostatic hypotension with syncope was still present 1 hour after stopping work and it was not until 1 hour and 15 minutes after the exertion that he could remain erect for the required 5 minutes. Even then the blood pressure had not yet returned to normal but fluctuated widely, with low systolic and narrow pulse pressures. In another subject (Chart 2) orthostatic syncope still occurred almost 2 hours after the exercise. Three hours after work, the erect posture was tolerated for 5 minutes, but the blood pressure was not yet normal. As a rule, there was recovery from syncope within 1 hour and from hypotension (abnormal group) within 2 hours. The progressive improvement of the orthostatic hypotension with time is indicated in Charts 2 and 3 by the increasing length of the successive erect periods before the development of hypotension and syncope.

Type of Subject. The physical characteristics of the subjects and their cardiovascular responses to various stimuli gave little basis for predicting who would develop this syndrome. There were but

minimal differences in the physical characteristics of the subjects of the 3 groups (Table 2). The men in the syncopal group averaged slightly taller (3 inches) and heavier (12 pounds) than the men in the normal group. There were no significant differences in the ages of the 3 groups. Physical fitness, as determined by fitness tests, was essentially the same in all 3 groups (Table 2). There were only slight differences in the cardiovascular responses to stimuli. Perhaps the responses in the syncopal group may be considered somewhat more labile than those in the other 2 groups (Table 3). The most marked differences lay in the higher pulse rates immediately after acute exhausting work and in the greater pressor response to the cold test in the syncopal group.

TABLE 2.—PHYSICAL CHARACTERISTICS AND PHYSICAL FITNESS OF THE SUBJECTS
(Data are the average for each group)

		Physical characteristics			Physical fitness	
Group	No. subjects	Age (yrs.)	Height (ft., in.)	Weight (lbs.)	Time of effort (min.)	Fitness score
Normal	14	26	5′6″	152	3.5	59
Abnormal	10	22	5′6″	158	3.4	52
Syncopal	9	23	5′9″	164	3.8	52

TABLE 3.—COMPARISON OF THE CARDIOVASCULAR RESPONSES OF THE THREE GROUPS TO STIMULI
(The data for each group are averages of the most marked response during the stimulus)

		Supine				Erect (70°)				Cold pressor test*				Mental problem†				Exercise‡			
		Blood pressure (mm. Hg)			Heart rate (per min.)	Blood pressure (mm. Hg)			Heart rate (per min.)	Blood pressure (mm. Hg)			Heart rate (per min.)	Blood pressure (mm. Hg)			Heart rate (per min.)	Blood pressure (mm. Hg)			Heart rate (per min.)
Group	No. subjects	Syst.	Diast.	Pulse		Syst.	Diast.	Pulse		Syst.	Diast.	Pulse		Syst.	Diast.	Pulse		Syst.	Diast.	Pulse	
Normal	14	119	73	46	71	118	88	30	91	134	91	43	71	135	92	43	89	166	78	88	145
Abnormal	10	117	73	44	71	112	85	27	94	134	92	42	74	129	86	43	86	149	69	80	166
Syncopal	9	122	73	49	77	115	86	29	101	141	98	43	70	136	88	48	67	158	75	83	172

* Two minutes of immersion of forearm in iced water.
† Five minutes of mentally multiplying 3 digits by 2 digits.
‡ Immediately on termination of pack test, subject seated.

The data suggest that post-exertional hypotension is more likely to occur in the tall, heavy subject with labile cardiovascular responses. The small number of subjects requires that this suggestion be taken with reservation.

Repeat Tests. With repetition of the work on subsequent days there is a tendency for improvement, and even disappearance, of the post-exertional orthostatic hypotension and syncope (Chart 4). Thus, of 5 subjects who were in the syncopal group after the first test, only 1 remained in the syncopal group following a repeat test; 2 moved into the abnormal group and 2 into the normal group. Similarly, of 7 subjects in the abnormal group after the first test, only 3 remained in the abnormal group following a repeat test, while 4 moved into the normal group. Ten men in the normal group on the first test remained in the normal group on repeat tests. In all instances the physical fitness scores were not significantly different on repeat tests from those on the initial tests.

Mechanism of the Hypotension. Several simple observations indicated the major rôle played by the motionless, dependent lower extremities in the production of the hypotension.

With the trunk still erect, raising the lower extremities to a horizontal position, so that the heels were on the same level as the buttocks materially raised the blood pressure (Chart 5). This maneuver did not, however, return the blood pressure to normal. A definite hypotension (abnormal group) still persisted but it was not so severe as to cause syncope. Syncope, however, promptly recurred when the legs

were lowered to the dependent position (Chart 5). Apparently the distribution of blood in both the splanchnic area and in the legs is responsible for the orthostatic hypotension and dependency of the lower extremities is critical to the production of the full effect.

During the orthostatic hypotension, movement of the fully dependent legs, without the accomplishment of much additional work, caused the blood pressure to rise from its low level to higher, and even normal, levels which were maintained as long as movement of the legs was continued (Chart 6). The movement of the legs here used consisted of bending the knee forward sufficiently for the heel to clear the foot board of the tilt table, the toe retaining contact with it. The legs were moved one at a time and alternately. With cessation of their movement orthostatic hypotension promptly returned (Chart 6).

When blood is prevented from flowing into the lower extremities of the upright subject, orthostatic hypotension does not occur; the blood pressure is sustained and a previously syncopal subject remains erect without difficulty (Chart 7). Just before the subject was tilted erect, the circulation to both legs was occluded by suddenly inflating, without venous stasis, blood pressure cuffs encircling both thighs. The cuffs were of standard 13 cm. width, backed by heavy cloth so that they did not balloon, and were inflated to 240 mm. Hg from pressure bottles. With the cuffs thus inflated orthostatic hypotension did not occur but it developed rapidly in preceding and subsequent erect periods when the thigh cuffs were not inflated (Chart 7).

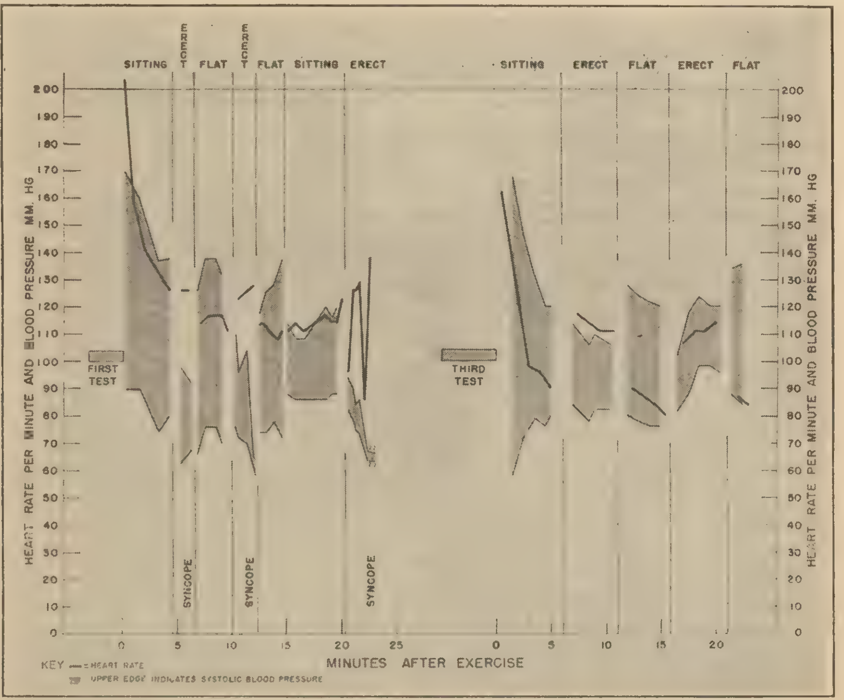

Chart 4.—Disappearance of post-exertional orthostatic hypotension with repetition of the inducing acute exhausting exercise. Marked orthostatic hypotension after the first test; normal blood pressure when erect after the third test.

Trapping as much blood as possible in

both lower extremities of a non-exercised subject failed to produce definite orthostatic hypotension, although some lowering of the systolic pressure and narrowing of the pulse pressure did occur (Chart 8). Reactive hyperemia was utilized to produce full dilatation of the vascular beds of the legs in which the blood was then trapped. With the subject flat, blood pressure cuffs about both upper thighs were inflated to 240 mm. Hg occluding the circulation to both legs. After 10 minutes the subject was tilted erect and 1 minute later both cuffs were deflated producing marked hyperemia of the dependent legs. In the first instance the cuffs were deflated to zero, permitting accumulation of blood in the dilated vascular beds of the legs under the influence of gravity alone; in the second instance they were deflated to 50 mm. Hg, trapping the blood under the influence of this resisting barrier as well as gravity. Chart 8 shows the marked drop in blood pressure immediately at the onset of reactive hyperemia and then the spontaneous and rapid recovery to a higher level, presumably as a result of vasoconstriction of other vascular areas of the body. The subject then remained erect without symptoms, in spite of the pooling in the legs of presumably as much

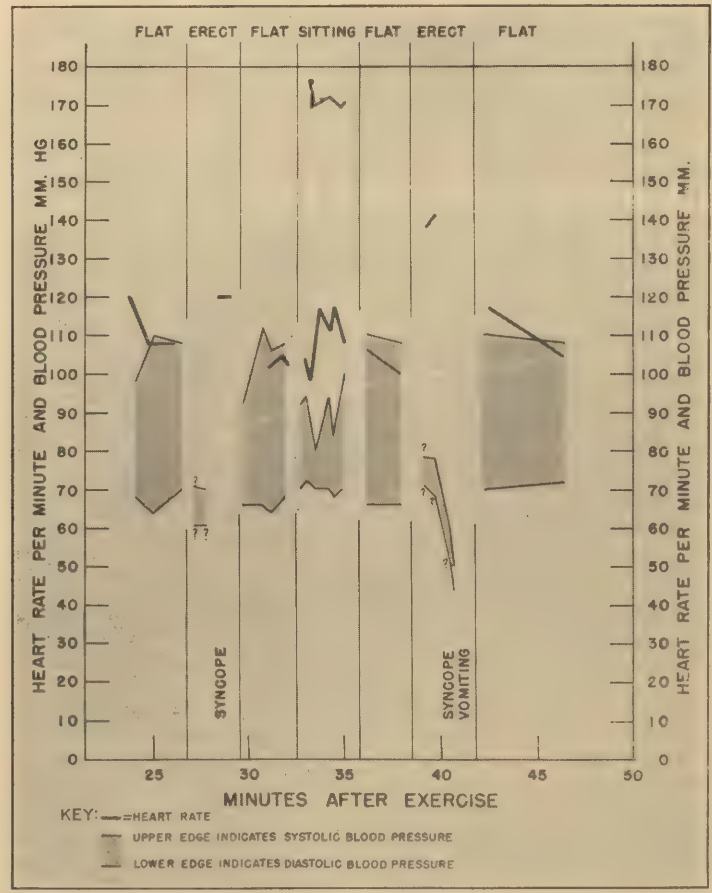

Chart 5.—Improvement in the post-exertional orthostatic hypotension when the legs are raised to a horizontal position at the level of the pelvis. (Indicated by diagram at top of sitting column.)

blood as their vascular beds would hold. This subject developed orthostatic hypotension following the pack test.

Orthostatic Hypotension Following Prolonged Enduring Physical Effort. Limited observations made after the completion of long-sustained physical work of lower energy expenditure indicated that post-exertional orthostatic hypotension occurs after this type of work as well as after acute exhausting physical effort. The 32 mile hike was attempted by 24 men; 22 finished, 2 dropped out after 28 miles. The responses of these 2 men are grouped with the others. Of the 24 men, 13 (54.2%) developed post-exertional orthostatic hypotension; 5 men (20.8%) were in the syncopal group and 8 men (33.3%) in the abnormal group (Table 4, Chart 9). This incidence is similar to that after acute exhausting exertion. After the hike test, the second erect period was omitted except in those subjects who developed hypotension during the first erect period and it is possible that late developing hypotensions were missed.

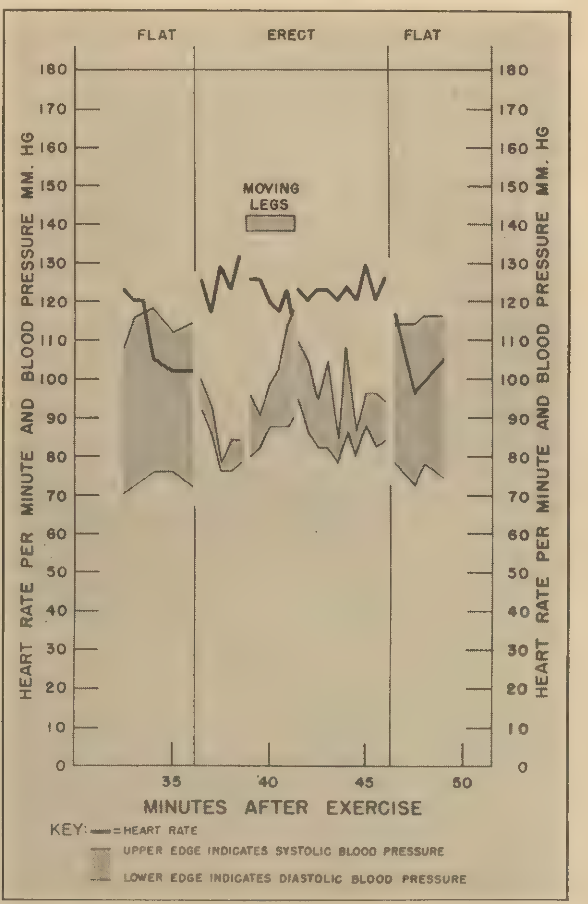

Chart 6.—Improvement in the post-exertional orthostatic hypotension when the dependent legs are moving.

The orthostatic hypotension induced by prolonged enduring work was very similar to that after acute exhausting work, Its development bore no relationship to the height, weight or age of the subjects

(Table 4) or to their physical fitness as determined by fitness tests and their general work performance. As after acute exhausting work, the orthostatic hypotension following the endurance hike often persisted for a long time. Usually the ability to remain erect, with a sustained blood pressure and without symptoms, returned in 1 to 2 hours after stopping work (Chart 9). In 1 instance, orthostatic hypotension was still present after a night's sleep, 12 hours after finishing the hike, and it was not until 16 hours after the hike that the erect posture could be main-

TABLE 4.—PHYSICAL CHARACTERISTICS OF THE SUBJECT GROUPS AND THEIR CARDIOVASCULAR RESPONSES AFTER 32 MILE HIKE

(The data for each group are averages of the final readings taken before position of subject was changed)

		Physical characteristics			First erect period					Second erect period				
						Blood pressure (mm. Hg)					Blood pressure (mm. Hg)			
Group	No. subjects	Age (yrs.)	Height (ft., in.)	Weight (lbs.)	Duration (min.)	Syst.	Diast.	Pulse	Heart rate (per min.)	Duration (min.	Syst.	Diast.	Pulse	Heart rate (per min.)
Normal . . .	11	23	5′8″	152	5.0	114	85	29	110					
Abnormal . .	8	22	5′8″	158	5.0	94	79	15	114					
Syncopal . .	5	25	5′7″	157	2.7	*92	*82	*10	‡120	2.0	†79	†68	†11	108

* Data for the 1 subject with obtainable blood pressure; blood pressure unobtainable in 4 subjects.

† Average of the 3 subjects with obtainable blood pressures; blood pressure unobtainable in 1 subject, and second erect period omitted on 1 subject.

‡ Average of 4 subjects; pulse missing on 1 subject.

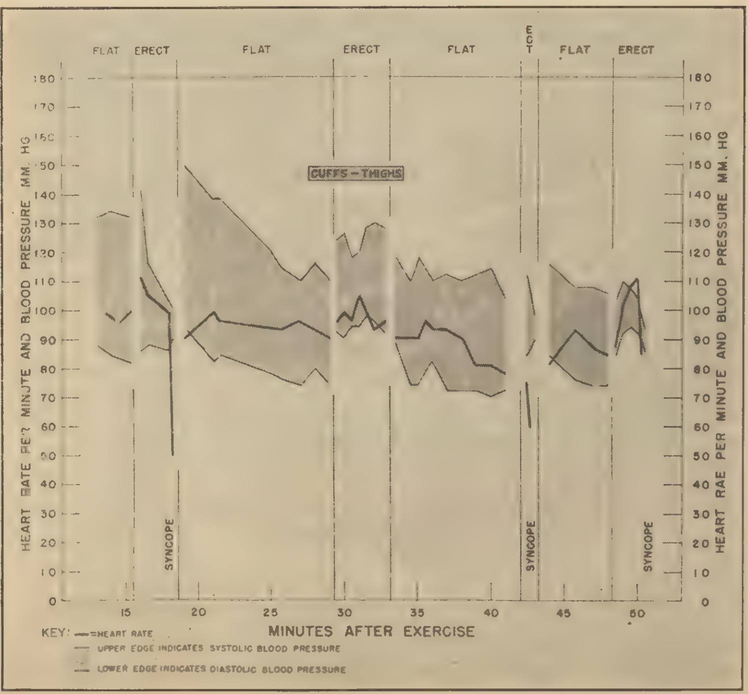

CHART 7.—Prevention of post-exertional orthostatic hypotension by excluding the circulation to the dependent legs. Just before the subject is tilted erect the cuffs about the thighs are inflated to 240 mm. Hg.

tained for 5 minutes. Even then the blood pressure was abnormal (Table 5). This subject also developed orthostatic hypotension after the pack test.

TABLE 5.—PERSISTENCE OF POST-EXERTIONAL ORTHOSTATIC HYPOTENSION IN A SUBJECT FOLLOWING AN ENDURANCE HIKE (32 MILES)

Time	Blood pressure subject erect (70°) (mm. Hg)	Heart rate (per min.)	Duration of erect posture	Remarks
Before hike	114/92	117	5 min.	No symptoms
1 hour after hike	Unobtainable	138	2 min.	Syncope
12 hours after hike (next morning)	Unobtainable	138	3 min.	Syncope
16 hours after hike	100/92	120	5 min.	Feels all right

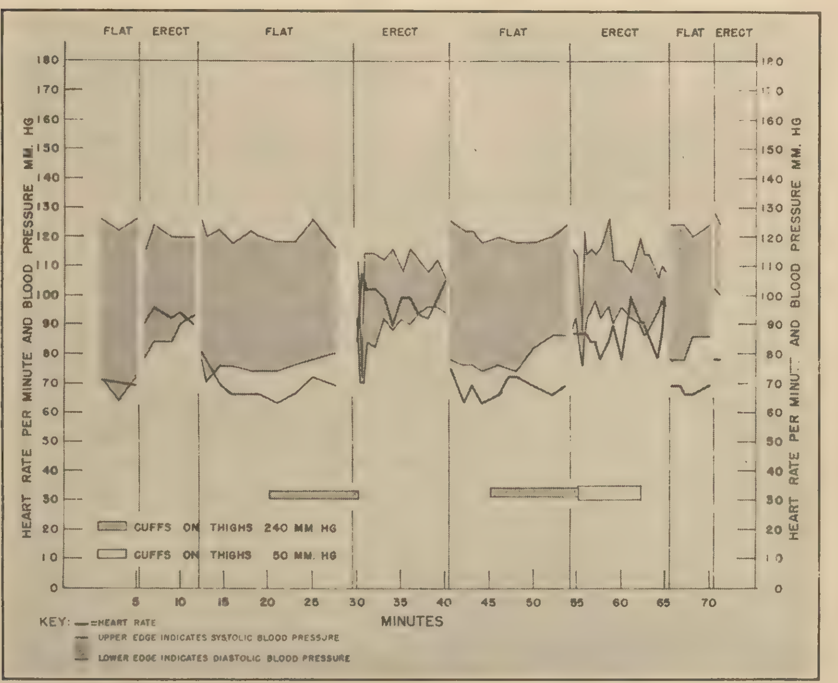

CHART 8.—Failure to produce orthostatic hypotension by trapping maximum amounts of blood in the dependent legs. Reactive hyperemia was used to induce maximal dilatation of the vascular beds of the legs and gravity plus venous occlusion to trap the blood in the dilated vessels.

Discussion. Combining the data following acute exhausting and prolonged enduring work into a group of 57 tests, post-exertional hypotension with syncope occurred in 14 (25%) and hypotension without syncope in 18 (32%). This agrees with the findings of other investigators. In a group of 50 students Mayerson[10] reported post-exertional orthostatic syncope in 17 (34%) and "poor response" in 10 (20%). Allen, Taylor and Hall[1] encountered orthostatic syncope in 17 (17%) of 100 aviation cadets who had run to exhaustion on a treadmill. In all of these studies, including the present one, the subjects have been healthy, young adult males, at times in especially good physical condition (athletes). One can only guess that the incidence in older age groups might be considerably higher, and the inducing physical effort less severe.

The erect position used in this study tends to minimize the incidence of orthostatic circulatory insufficiency: (*a*) the erect periods were maintained for only 5 minutes; others have required 10 to

20 minutes, and (*b*) the body weight was borne by the legs, permitting muscle tonus to aid in the venous return from the legs; others have eliminated this by supporting the body from the pelvis or shoulders. Since the erect man normally supports his weight on his feet, it was felt that observations performed in this manner would come nearer to reproducing the conditions under which this syndrome might occur in everyday life.

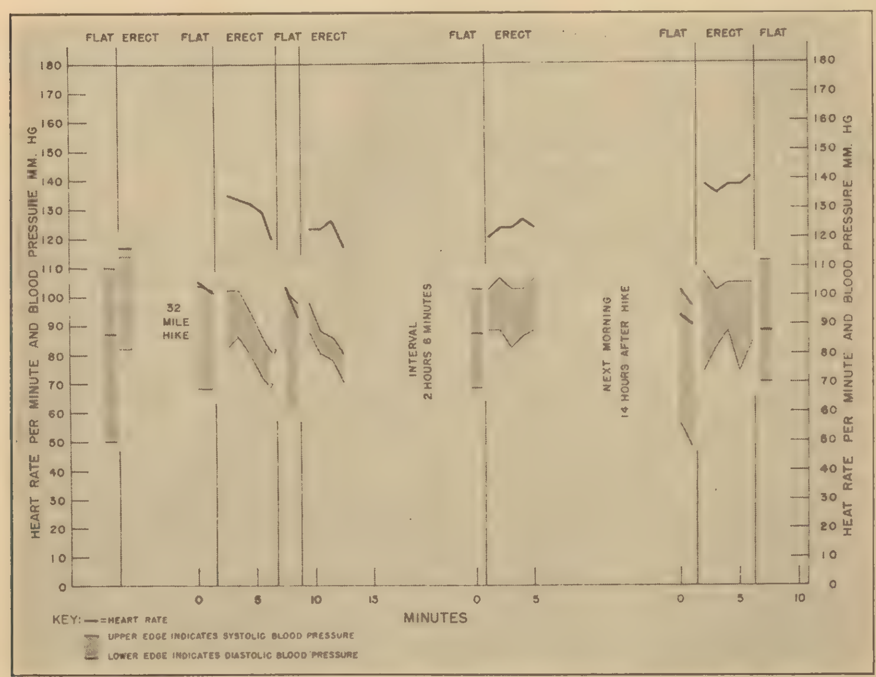

CHART 9.—Orthostatic hypotension with syncope following moderate work of long duration (32 mile hike).

The failure to establish a clear-cut relationship between post-exertional orthostatic hypotension and bodily configuration, tests of cardiovascular lability, or physical fitness gives, at present, no basis for predicting who will develop hypotension after physical effort. It can, however, be prevented by training, through repetition of the inducing physical work.

The present study does not explain completely the mechanism which permits the development of orthostatic hypotension after exertion, but suggests as a plausible explanation an inadequate return of blood to the heart. The beneficial effects resulting from elevating the legs while the trunk remains erect, moving the legs when they are dependent, and excluding the circulation from the dependent legs, all suggest that the circulation in the lower extremities is at fault and responsible for the decreased venous return. The question is the nature of this circulatory fault.

Two possibilities present themselves: (*a*) marked vasodilatation of the vascular tree of the legs and (*b*) failure of the muscular venopressor mechanism in the legs. The first of these assumes such a marked dilatation (exercise induced) of the vascular tree of the legs that the total vascular bed of the body is now disproportionately greater than the blood volume available to fill it at a normal pressure. The vascular tree of legs would contain an excessive amount of blood which would be flowing. The second possibility assumes that such a vasodilatation is not by itself capable

of producing the hypotension, as long as blood flow through the legs persists, and suggests that the blood in the legs has become stagnant through the failure of the muscular venopressor mechanism to move it onward and upward. The blood in the legs would be relatively non-moving. Since both mechanisms would reduce the amount of blood at heart level and induce hypotension, it may be considered an academic point to chose between them. Nevertheless, several observations suggest that failure of the venopressor mechanism may be a more critical factor than extensive vasodilatation. These are: (*a*) the delayed development of orthostatic hypotension in some subjects who stand without difficulty in the first erect period, when vasodilatation is greatest, and then develop hypotension in subsequent stands when vasodilatation is presumably diminishing (Chart 3); (*b*) the persistence of the orthostatic hypotension for long periods (several hours) after cessation of exertion, when the vascular dilatation may be considered to have largely passed off (Charts 2 and 3); (*c*) the recovery of the blood pressure from hypotensive toward normal levels when the dependent legs are moved without significant additional work (Chart 6); and (*d*) the failure to induce a similar hypotension and syncope when maximum amounts of blood are trapped in the dependent legs of erect but non-exercised subjects, who develop orthostatic hypotension after exercise (Chart 8). In this last instance, the large blood mass in the legs is presumably still moved forward by the unaltered muscular venopressor mechanism of non-exercised legs. While the above observations suggest that a reduced muscular tonus with a depressed venopressor mechanism in the legs plays the major rôle in the hypotension, this point has not been substantiated by direct experimentation. Neither has the degree of vasodilatation in the legs been measured.

This study, and similar ones in the literature, have all dealt with work performed either largely or wholly by the lower extremities. The critical, parallel observations following work of the upper extremities alone have yet to be carried out.

It is desirable to point out again that post-exertional orthostatic hypotension is not limited to acute exhausting effort and that it occurs with almost equal frequency, and with similar physiologic changes, after prolonged effort at a lower work rate. This, together with the striking persistence of the orthostatic hypotension for long periods after cessation of work may be of significance to clinical medicine in an understanding of the collapse states, and even death, which are encountered after physical effort.[4] If healthy, young men can develop circulatory failure while erect after exercise, one may guess that similar circulatory changes are not only likely in the older age groups, but that they may be more readily induced, more severe in their manifestations and capable of serious consequences. The effects of physical effort in the older age groups, and the relationship of the changes thereby induced to subsequent disability appears to be a fertile field for study.

Summary. 1. Orthostatic hypotension developed in approximately one-half of normal young men following vigorous exercise of the lower extremities. It followed prolonged moderate work as well as acute exhausting effort.

2. In one-half of those who developed orthostatic hypotension (one-fourth of all subjects) the hypotension was so severe that syncope resulted.

3. The orthostatic hypotension often persists for long periods, over 1 hour, after cessation of the inducing physical effort.

4. The causative factor appears to be a pooling of blood in the dependent lower extremities, presumably due to failure of the muscular venopressor mechanism in the legs, plus a work induced dilatation of their vascular beds.

5. During the orthostatic hypotension, maneuvers which move blood out of the lower extremities, or exclude blood from them, relieve the hypotension.

It is a pleasure to acknowledge the assistance of Major Edgar A. Blair, Inf., A.U.S. in these studies and the technical participation of Tec. 3 Howard Golden and Tec. 4 Wayland James.

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THERMAL EXCHANGES OF MAN AT HIGH TEMPERATURES

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Studies of the physiological responses of men to high environmental temperatures require for their most general application a means of transfer of data secured under particular environmental conditions to other intermediate but untested conditions. This need would be fulfilled if there were available functional relationships capable of describing thermal stress to the man in terms of the various environmental factors. Such relationships for limited ranges of environmental conditions are available for convection (1a, b, c, d) and for still more limited ranges for evaporation (1d, e). Thermal exchange by low temperature radiation appears to be well founded on both theoretical and experimental grounds (1f, 2a). The need for descriptive relationships of thermal exchange has led to attempts to extrapolate the meager data now available to conditions out of the range of the original experiments (3).

The ideal procedure for establishing these relationships is by means of complete calorimetry. The technical difficulties and elaborate equipment involved in this approach become almost prohibitive when higher wind velocities and working subjects are studied. The simpler method of partial calorimetry has been used at the Pierce Laboratory with considerable success over normal temperature ranges (1). This approach is less satisfactory at more severe environmental conditions largely because of the greater difficulty of reaching thermal equilibrium and the consequent higher rates of storage (subject to considerable error in estimation). However, the potential usefulness and need (especially during the war) of even roughly quantitative descriptions of convection and evaporation at high thermal loads justifies their study by the method of partial calorimetry. The results of such a study are presented in this report.

The principle involved in the use of partial calorimetry to allocate thermal exchange into its several components is contained in the statement that at equilibrium (no increase or decrease in heat content of the body) the rate of thermal flow outward across the envelope of reference (skin) is equal to the rate of thermal flow inward, or, in the absence of thermal equilibrium, that these two rates differ by the rate of change in the heat content of the body. These considerations apply regardless of the source of heat (metabolism, environment, stored heat) or the nature of its transfer (convection, conduction, evaporation).

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[1] Now at Children's Hospital Research Foundation, Cincinnati, Ohio.

[2] Now at New York University College of Medicine, New York, New York.

[3] Now at University of Pennsylvania, Philadelphia, Pennsylvania.

[4] Now at Industrial Hygiene Foundation of America, Pittsburgh, Pennsylvania.

This statement can be mathematically expressed as $M + S + E + C + R = 0$ where the symbols represent, respectively: M, the rate of metabolic heat production, always positive in sign; S, the rate of storage (the rate of gain or loss in heat content of the body), positive in sign when the body heat content decreases, negative when heat is gained by the body; E, the rate of evaporative heat loss, always negative in sign; and C, the rate of thermal exchange by convection, and R by radiation, both positive when delivering heat to the body and negative when removing it. Of these variables, M can be determined from the rate of oxygen consumption; S from the changes in rectal and skin temperature, unfortunately, with uncertain reliability; and E from the evaporative weight loss of the subject and the latent heat of vaporization. With M, S, and E available, the sum of $C + R$ can be calculated by difference. The separation of C from R can be accomplished mathematically by taking advantage of the fact that R is independent of wind velocity, or alternatively R can be calculated from skin and wall temperatures by accepted principles and subtracted from the sum $C + R$.

Utilizing the above principles, 4 subjects were studied while standing nude, standing clothed and walking clothed at 5 wind velocities in each of 7 environmental conditions, representing 3 moisture contents at 5 air temperatures (table 1). It has been possible to make a fairly complete analysis of the standing-nude experiments. The data from the clothed experiments give less satisfactory results.

Test conditions and procedures. The experiments were carried out on 4 healthy young men whose physical characteristics are given in table 2. After preliminary training in the cool, they were trained and acclimatized to heat by working for 4 hours per day as follows: 4 days at D.B.[5] 120°F., W.B.[6] 78°F.; 2 days at D.B. 120°F., W.B. 86°F.; 2 days at D.B. 94°F., W.B. 91°F.; 1 day at D.B. 96°F., W.B. 92°F.; and finally 1 day at D.B. 120°F., W.B. 88°F. During this period test clothing was worn and activity and environment were at least as severe as during the actual test days. Acclimatization produces well adjusted subjects with minimal changes in heat storage.

Three subjects were used, with the fourth held in reserve, but helping in the hot room and receiving the same exposure as the 3 test men. On the eleventh test day the man in reserve replaced an original subject who was removed because of an upper respiratory infection. With this exception, the subjects were in good condition throughout the study. They spent 7½ hours in the hot room each test day, but slept in barracks maintained at normal temperatures. Data were collected on 5 days in each week. Sunday was spent out of the hot room and Monday was devoted to reacclimatizing 4-hour marches.

The 7 environments were studied in a regular sequence, one wind velocity being covered each day (table 1). The completion of each cycle of 7 environments was followed by a 'Base Day'. The coefficients of convection, radiation and evaporation for all 'Base Days' agreed well with each other, indicating that the

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[5] D.B. dry bulb temperature.

[6] W.B. wet bulb temperature.

TABLE 1. *Environmental conditions studied*

Number in parentheses, environment code number; number with degree sign, wet bulb temperature F.

DRY BULB TEMP.	VAPOR PRESSURE mm.Hg		
	13	25	36
°F.			
90	(1) 69.5°	X	X
96	(2) 71.5°	(5) 82.8°	(7) 91.0°
105	(3) 74.0°	X	X
120	(4) 78.0°	(6) 88.0°	X

Wind velocities

CODE	FT/MIN.
a	30
b	75
c	150
d	300
e	600

Sequence of environments

The number refers to environment, the letter to wind velocity.

WEEK[1]	M(ACC)[2]	T	W	T	F	S
1	120–88	Bd[3]	6a	7e	5e	2a
2	120–78	1c	3e	4a	Bd	6c
3	96–91	7e	5a	2c	1e	3a
4	120–78	4c	Bd	6e	7a	5c
5	120–78	2e	1a	3c	4e	Bd
6	120–88	6b	7d	5b	2d	1b
7	120–88	4d	Bd	6d	7b	5d
8	120–88	2b	1d	3d	4b	Bd

[1] Starting 9 October, 1944.

[2] Acc = Re-acclimatization, no data collection.

[3] Bd = Base Day; D.B. 120°F—W.B. 88°F. 300 ft/min.

TABLE 2. *Physical characteristics of the subjects*

SUBJECTS	COMPLEXION	AGE	HEIGHT	WEIGHT	SURFACE AREA
		years	*cm.*	*kg.*	M^2
Mil	light	20	166	62.4	1.68
Lon	light	22	170	65.5	1.75
God[1]	brunette	20	185	62.5	1.82
McG	brunette	22	177	74.4	1.90

[1] God replaced McG after 11 test days.

physiological response of the subjects to the same conditions remained reasonably constant throughout the study. During the 8 weeks working metabolism fell by 10%; rectal temperatures and heart rates showed little consistent change.

The tests were carried out in a sheet-metal wind tunnel (5½ ft. wide, 7½ ft. high and 20 ft. long) in the hot room. Six 24-inch fans at the discharge end of the tunnel produced air flow, the velocity of which was changed by adjusting either the fan speed or the louvres (located just upstream from the fans) or both. The entering end of the tunnel was packed over the entire section with 30-inch lengths of 8-inch galvanized pipe lying in the axis of the tunnel. This served as an air straightener and protected the inside of the tunnel from outside air disturbances. Air movement was virtually uniform across the cross-section of the tunnel to within 6 inches of the walls. A treadmill on which the subject stood or walked constituted the central portion of the tunnel floor. The inside surfaces of the tunnel were painted flat black. Dry and wet bulb temperatures inside the tunnel were maintained at the designed conditions plus or minus 1°F. and were uniform laterally. Vertically there were gradients between head and floor levels of 1°F. or less for the cooler situations and not more than 3°F. for the hottest conditions.

On test days 3 separate experiments were performed on each of the 3 subjects in the same sequence: walking clothed in the morning, and standing nude and standing clothed in the afternoon. The subject always faced into the air flow and was accompanied in the tunnel by one observer who remained behind the subject at all times.

The walking tests were performed on the treadmill at 3 m.p.h. and a 3% grade. This led to metabolic rates of approximately 160 Cal/M^2/hr. The standing metabolic rates were in the range 40–60 Cal/M^2/hr.

All test periods were 30 minutes long and were preceded by an equilibrating period designed to reduce storage during the test period. Before the walking experiments the equilibrating period consisted of a 60-minute walk on the hot room track (2.7 m.p.h. carrying a 20-lb. pack) followed by a 10-minute walk on the treadmill at the test wind velocity. Before the standing experiments it consisted of a 10-minute stand outside the tunnel either clothed or nude.

During the clothed tests the subjects wore well laundered, two-piece, herringbone twill (HBT) fatigue uniforms, light wool socks, cotton underwear shorts and field shoes. To avoid sweat loss by drippage the jacket was tucked into the trousers, the trouser legs into the sock tops, and the jacket cuffs into 4-inch wristlets made of sock tops. In the nude experiments the subjects stood on wooden clogs in a shallow tray containing mineral oil which collected the dripping sweat. In the clothed experiments a dry suit was donned immediately at the start of the test period just after the equilibrium period. In each experiment water salted to 0.1% was given in amounts approximating sweat loss.

Data collected. The environmental conditions inside the wind tunnel were determined during each test period as follows: *a*) wet and dry bulb temperature, 6 feet and 1 foot above floor level, three times per test period, by calibrated motor-driven psychrometers; *b*) wall temperature, of the 6-tunnel surfaces, by radiometer at the beginning and end of both the morning and afternoon tests; *c*) velocity of air flow at a point waist high, 4 feet in front of the subject, twice each period by a velometer and 3 times each period by hot wire anemometer.

The following data were obtained on each subject: *a*) rectal temperature by

calibrated clinical thermometers at the start and end of each test period; *b*) skin temperature at the start, mid-point and end of each test period by radiometer when nude, by contact thermocouples when clothed; *c*) clothing temperature by radiometer at the same time as skin temperature; *d*) oxygen consumption in the walking tests during the first and last 10 minutes of each period by an open circuit system, and in the standing tests for the entire 30 minutes by a closed circuit system; *e*) heart rate at the beginning, mid-point and end of each period by palpation; *f*) evaporated sweat loss, determined by the difference in weight at the start and end of a test period of the subject plus his accessories (clothing in the walking experiments, clothing and towel in standing clothed experiments and towel and drip pan in nude experiments); *g*) total sweat loss, the evaporated sweat loss plus the increase in weight of the accessories above mentioned.

Treatment of data. Weighted skin and surface temperatures were calculated for each of the 3 sets of readings in each period according to the weighting factors shown in table 3. These factors are based on the surface area measurements of Hardy and Dubois (2b). The necessary readjustments required by the small number of zones measured were made by grouping unmeasured zones with those measured zones which in previous studies had been observed to have similar temperatures, admittedly a dangerous expedient. It receives some justification, however, in that at the high temperatures here observed, the maximum range of variation of skin temperatures from zone to zone is small. The emissivity of both skin and clothing was taken as unity. The initial and final weighted skin temperatures were used in the calculation of storage and the average of the 3 values per period was used in calculation of vapor pressure and temperature gradients.

The 6 readings of dry bulb temperatures in each period were averaged to give the value used. The wet bulb temperature was similarly obtained. Vapor pressure was calculated from these averaged dry (T_a) and wet bulb temperatures (T_{wet}) by the formula:

$$P_{H_2O} = P_{H_2O T_{wet}} - 0.265\,(T_a - T_{wet}).$$

This expression was based on calibration of the psychrometers used in this study against dew-point measurements.

Wall temperature was taken as the mean of the measurements of the six surfaces, and the average of the initial and final wall temperatures thus calculated was used. Wall temperatures deviated only slightly from air temperatures.

Air velocity was obtained by averaging the 5 measurements made per period.

The heat equivalent of the oxygen consumption was calculated in the usual way; the actual R.Q. was used to determine the caloric equivalent of oxygen in the open circuit runs, while the value 4.83 Calories/liter O_2 was used in the standing experiments.

The actual interval between the initial and final weights of the subject were used in calculating evaporation and sweat rates. This interval was longer than the tunnel exposure by about 2 minutes. Sweat loss, total and evaporated, was calculated from weight differences and water intake, corrections being made for

TABLE 3. *Factors used for calculation of weighted skin and surface temperatures*

HARDY, DUBOIS AREAS		ZONES MEASURED	WEIGHTING FACTORS				
			Nude Skin T_s	Clothed			
				Standing		Walking	
Zone	Area			Skin T_s	Surface T_e (d)	Skin T_s	Surface T_e (d)
Head	0.07	Cheek	0.07	0.07	0.05	0.14e	0.12e
Trunk	0.35	Chest Back	0.18 0.17	0.35tb	0.19 0.17	0.35tb	0.19 0.17
Arms	0.14	Upper arm	0.14	0.14t	0.15	0.14t	0.15
Hands	0.05	Palm	0.05	0.05	0.04	0.05	0.04
Thigh	0.19	Thigh	0.39a	0.19t	0.40a	0.19t	0.33f
Legs	0.13	Calf		0.20tc		0.13t	
Feet	0.07						

t—Obtained by thermocouple; all other temperatures by radiometer.

a—Feet and legs grouped with thigh.

b—Back and chest grouped.

c—Feet grouped with calf.

d—Because of increased surface area of clothed man, head and hand factors decreased, all other factors increased.

e—Foot grouped with cheek.

f—Legs grouped with thigh.

TABLE 4. *Relation of clothed man surface area to nude man surface area*

SUBJECT NO.	TYPE[1]		Height	Weight	SIZE		SURFACE AREA M^2					RATIO $\frac{\text{CLOTHED MAN S. A.}}{\text{NUDE MAN S.A}}$
	Height	Weight			Jacket	Trousers	Jacket	Trousers	Jacket & trousers	Clothed man[2]	Nude man	
			cms.	kgm.								
1	S	L	163.8	45.0	34R	30–33	0.875	1.057	1.932	2.208	1.45	1.52
2	I	L	168.9	57.5	34R	32–33	0.981	1.146	2.127	2.439	1.64	1.48
3	T	L	183.5	57.3	36R	32–33	1.038	1.206	2.244	2.577	1.75	1.47
4	S	I	157.5	60.5	34R	30–33	0.830	1.057	1.887	2.191	1.60	1.36
5	I	I	172.1	68.2	34R	32–33	0.930	1.167	2.097	2.437	1.79	1.36
6	T	I	193.0	89.2	38L	34–33	1.086	1.180	2.266	2.680	2.18	1.22
7	S	H	161.3	66.6	34R	34–33	0.882	0.992	1.874	2.195	1.69	1.29
8	I	H	176.5	85.5	38L	38–33	1.045	1.278	2.323	2.703	2.00	1.35
9	T	H	182.9	101.4	40R	40–33	1.169	1.424	2.593	3.013	2.21	1.36

[1] S = Short; I = Intermediate; T = Tall; H = Heavy; L = Light.

[2] = Surface area of head + hands + feet + clothing = 0.19 nude man S.A. +clothing S.A.

weight loss due to excess weight of CO_2 excreted over O_2 consumed and for loss of water from the lungs. The excess CO_2 was determined by the formula, $(CO_2 - O_2)$ grams/hour $= 118 \times O_2$ (L/min)(RQ $- 0.727$). In the standing experiments the R.Q. was taken as 0.825.

Surface area of clothed man. The problem of the clothed surface area is a difficult one involving not only the actual area but also the effective area as determined by the folds. From measurements of exposed clothing areas carried out on 9 men representing different body builds the ratio of clothed man surface area to nude surface area was calculated. The results are shown in table 4. These are maximum values since they are made on stretched clothing. It seems not unreasonable that the effective ratio would ordinarily fall in the range 1.20 to 1.35. This series did not include the subjects used in the calorimetry studies. Because of the variation from man to man, and even from time to time, depending on how the folds fall, the coefficients of thermal exchange for the clothed men have been calculated using the nude surface area. This gives the most predictable area and permits future correction should an acceptable factor for clothed men be found. Thus the coefficients for clothed men here calculated should be higher than those for nude men by the ratio of the two surface areas (1.20 to 1.35:1).

Notation, units and calculation of thermal exchange:

$C + R$ was calculated from the basic heat equation

$$M + E + S + C + R + W = 0$$

where the terms have the following significance and origin:

1. *Evaporation*

E' = Total heat exchange by evaporation, Cal/M^2/hr.
= (kg sweat loss/hr/M^2 − CO_2 excess/hr/M^2) 575.
H_e = Heat exchange by evaporation in the respiratory tract, Cal/M^2/hr.[7]
E = $E' \mathbin{\dot{-}} H_e$ = Heat exchange by evaporation from the surface of the body, Cal/M^2/hr.

[7] H_e was estimated by making the assumptions indicated below as to vapor pressure of expired air and inspired spirometer air.

Walking (open circuit system):
$H_e = 0.0418\ (P_a - P_1)\ VR$, where
P_a = vapor pressure of tunnel air,
P_1 = vapor pressure of expired air,
VR = ventilation rate, liter/min.

Standing (closed circuit system):
$H_e = 0.0418\ (P_{sp} - P_1)\ VR$, where
P_{sp} = spirometer air vapor pressure taken as 90% saturated,
P_1 = 44.6 mm Hg, except for ambient temperatures of 105°F. and above, where 49.2 mm Hg was taken,
VR = ventilation rate, liter/min.; estimated from rate of oxygen consumption by a correlation between the two used in this laboratory.

$P_{(a,s,e)}$ = Vapor pressure of water in air, on skin, clothing, mm.Hg

$E/\Delta P$ = Coefficient of evaporation, Cal/M^2/hr/mm.Hg ('$(a - e)$' or '$(a - s)$' following a coefficient signify that ΔP or ΔT has been calculated from the difference between air and surface or air and skin respectively.)

2. *Convection and radiation*

$(C + R)'$ = Total heat exchange by convection and radiation, Cal/M^2/hr, defined by $(C + R)' + M + S + E + W = 0$

H_c = Heat exchange by convection in the respiratory passages, Cal/M^2/hr.[8]

$C + R = (C + R)' - H_c$ = Heat exchange by convection and radiation from the surface of the body, Cal/M^2/hr.

$T_{(a,\, w,\, s,\, e,\, r)}$ = Temperature of air, wall, skin, clothing, rectum, °C.

$\dfrac{C + R}{\Delta T}$ = Combined coefficient of convection and radiation, Cal/M^2/hr/°C.

$C/\Delta T$ = Coefficient of convection, Cal/M^2/hr/°C.

$R/\Delta T$ = Coefficient of radiation, Cal/M^2/hr/°C.

3. *Metabolism*

M = Metabolic heat production, Cal/M^2/hr.

4. *Water ingested*

W = Heat exchange by water intake, Cal/M^2/hr. = kgm. water/hr/M^2 × $(T_{\text{water}} - T_r)$

5. *Storage*

$$S = \text{Storage, Cal/M}^2\text{/hr.} = \frac{(0.83)\ (\text{weight in kgm})\ (0.67\,\Delta T_r + 0.33\Delta T_s)}{(\text{Time interval, hours})\ (\text{Surface area, M}^2)}$$

where 0.83 represents the average specific heat of the body and 0.67 and 0.33 are the fractional portions of the body conforming to average temperatures of T_r and T_s, respectively (2b).

Legitimate corrections were made even though their order of magnitude was low in relation to the probable error of the measurements. Thus, the weight-

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[8] H_c was estimated from the ventilation rate and an assumed temperature of expired air thus:

$$H_c = 0.0187\ (T_a - T_{\text{exp.}})\ VR, \text{ where}$$

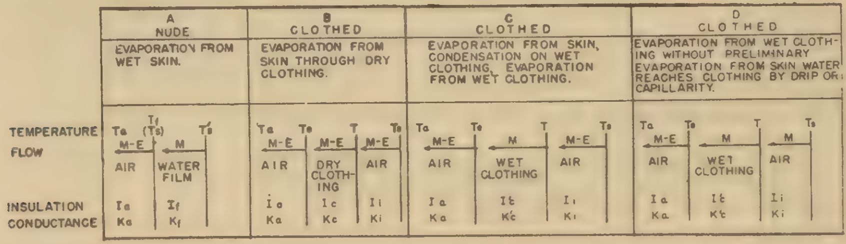
T_a = Temperature of ambient (inspired) air,

$$T_{\text{exp.}} = \frac{T_r + T_s}{2} \text{ and,}$$

VR as defined under H_e.

loss correction for excess CO_2 was at most only 12 grams/M^2/hr. H_e in the walking experiments ranged from about 5 Cal/M^2/hr. in the humid environments to about 15 Cal/M^2/hr. in the dry environments. In the standing experiments (closed circuit system) H_e was independent of ambient vapor pressure, and ranged from -1 to $+4$ Cal/M^2/hr. H_c was ordinarily less than 1 Cal/M^2/hr. in the standing experiments at 120°F, increasing in the walking experiments to about 2.5 Cal/M^2/hr.

Reliability. Granting the validity of the determination of the thermal quantities E, M and S, the question arises whether the E experimentally measured is equivalent to the E required by the basic heat equation.



	A	B	C	D
1)	$E - M = C + R$	$T_s - T = I_i(M-E)$	$T_s - T = I_i(M-E)$	$T_s - T = I_iM$
2)	$M - E = -(C+R)$	$T - T_e = I_c(M-E)$	$T - T_e = I_c' M$	$T - T_e = I_c'M$
3)	$K_a(T_a - T_s) = C+R$	$T_e - T_a = I_a(M-E)$	$T_e - T_a = I_a(M-E)$	$T_e - T_a = I_a(M-E)$
4)	$\frac{T_a - T_s}{I_a} = C+R$	$T_s - T_e = (I_i + I_c)(M-E)$	$T_s - T_e = (I_i + I_c')\left(M - E\frac{I_i}{I_i + I_c'}\right)$	$T_s - T_e = (I_i + I_c')M$
5)	$\frac{T_s - T_a}{I_a} = -(C+R)$	$T_s - T_a = (I_i + I_c + I_a)(M-E)$	$T_s - T_a = (I_i + I_c' + I_a)\left(M - E\frac{I_a + I_i}{I_i + I_c' + I_a}\right)$	$T_s - T_a = (I_i + I_c' + I_a)\left(M - E\frac{I_a}{I_i + I_c' + I_a}\right)$
6)	$\frac{T_s - T_a}{I_a} = M - E$	$\frac{T_s - T_e}{T_e - T_a} = \frac{I_c + I_i}{I_a}$	$\frac{T_s - T_e}{T_e - T_a} = \frac{I_i + I_c'}{I_a}\,\frac{M - E\frac{I_i}{I_i + I_c'}}{M - E}$	$\frac{T_s - T_e}{T_e - T_a} = \frac{I_i + I_c'}{I_a}\,\frac{M}{M - E}$
7)	$T_s - T_a = I_a(M-E)$			
8)	$T_s' - T_f = I_f M$			

FIG. 1. EQUATIONS OF THERMAL FLOW FOR EVAPORATION FROM VARIOUS SURFACES. In all cases it is assumed that $S = 0$, and that the condition $C + R + M + E = 0$ is fulfilled. E is always negative for the conditions considered here. The rates of heat transfer by C and by R are combined in a common coefficient $K = 1/I$.

Consider first evaporation from wet skin in the nude man illustrated in figure 1 A. In this situation the rate of heat flow to T_f from the environment will be equal to $K_a(T_a - T_f)$, where K_a represents the combined coefficients of C and R. Since the only other source of heat to the surface T_f is M(taking $S = 0$) and since for a steady condition of heat flow, the rate of access of heat to the surface must equal the rate of heat dissipation, the following condition is fulfilled: $K_a(T_a - T_f) + M + (-E) = 0$. Since $K_a(T_a - T_f) = C + R$, the basic equation is satisfied with respect to the surface T_f. Since radiometric measurement of the temperature of wet skin actually measures the water film temperature, the significant temperature for the surface of reference is actually obtained.

Three possible paths of evaporation from clothed men are illustrated (fig. 1 B, C, D). Equations of heat flow for these situations are developed in an analogous manner. For convenience, they are arranged as equations of temperature difference (see Burton, 6). Note that equations 3B, C and D all have the

same form $I_a(M - E) = (T_e - T_a)$. Since this is equivalent to $K_a(T_e - T_a) = M - E$, and $K_a\ (T_e - T_a) = C + R$ for the clothing surface, the required condition is fulfilled for these 3 conditions of evaporation from the clothed man, when T_e is taken as the temperature of reference for $C + R$.[9] In case a water film of appreciable thickness is present on the clothing the correct surface temperature is no longer T_e but the temperature of the water film; this is still the temperature actually measured.

The reliability of $C + R$ by thermal difference where $C + R = -(-E) - M - S - W$ is limited by the accuracy of estimation of E, M, and S. In the calculation of E, use of the same value for the latent heat of vaporization for all skin temperatures and disregard of the energy involved in vapor expansion or change in temperature lead to errors which appear to be minor relative to other uncertainties. Also relatively minor is the error involved in disregarding frictional loss in correcting M for external work in the walking experiments.

A reliable calculation of storage from the data available and by the procedure here used appears to be hopeless. The internal heat distribution undoubtedly varied during the test period, making untenable the use of any fixed distribution ratio for calculation of storage. Moreover, the assumption that weighted rectal

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[9] This conclusion is not invalidated by the fact that the amount of evaporation required for steady state conditions varies with the path of evaporation and with the insulation of the various layers through which the heat must flow. The difference in evaporation can be thought of as producing different temperatures of the outermost surfaces. Thus, in the case of evaporation from wet unclothed skin (fig. 1A) the equations of heat flow through the water film and from the water surface to the environment are:

$$T_s' - T_f = I_f M \qquad \text{(skin to water film)}$$

$$T_f - T_a = I_a(M - E) \qquad \text{(water to air)}$$

which upon adding gives

$$T_s' - T_a = (I_a + I_f)\left(M - E\,\frac{I_a}{I_f + I_a}\right) \qquad \text{(skin to air)}$$

These equations show, first, that T_f is lower than the true skin T_s' temperature by $I_f M$, and second, that because of this lower temperature and the resulting increase in the rate of $C + R$ transfer, the necessary E for equilibrium is higher than the E for an infinitely thin water film ($I_f = 0$) by the factor $\frac{I_a + I_f}{I_a}$. The extra evaporation can be thought of as producing the lower T_f.

As noted above, a similar analysis of evaporation from clothed men leads to the requisite equivalence of equations 3B, C, and D despite the fact that E will vary with the path of evaporation. Extension of the analysis permits estimation of the relative rates of evaporation required by the three possible routes of evaporation for identical skin temperatures and environmental conditions. Thus, since for equal temperature gradients from air-wall to skin ($T_s - T_a$) the right-hand members of equations 5B, C, and D are equal and differ only in the coefficient of E to preserve equality, E must increase as its coefficient decreases. Hence for the same skin temperatures and environmental conditions E will be largest when evaporation occurs initially from the skin and recondenses and re-evaporates from the clothing (smallest coefficient) (C, 5), and smallest when the evaporation occurs from the skin without subsequent condensation in the clothing (largest coefficient) (B, 5). Initial evaporation from the clothing (D, 5) requires an E intermediate between these two situations.

and skin temperatures are representative of any predictable mass of tissue remains questionable. With these uncertainties success in partial calorimetry depends largely on the degree to which negligible changes in storage are incurred. Because of the above sources of error, and those incurred in the temperature measurements themselves, useful study of the $C + R$ exchange has been restricted to the two 120°F. environments. In these environments the large $C + R$ exchange reduces the relative importance of these sources of error.

The reliability of the coefficients of $C + R$ depends not only on the thermal difference, $C + R$, but also on the accuracy of the temperature differences $T_a - T_s$ and $T_a - T_e$. Two factors enter into the reliability of the $T_a - T_{(s \text{ or } e)}$, the accuracy of the individual measurement and the reliability of the weighting formula.

The weighting procedure for an average skin temperature (T_s) is reasonably reliable inasmuch as variations in temperature of individual areas are small. In the clothed man the weighting procedure for an average surface temperature (T_e) is less reliable because of the greater temperature differences between individual areas resulting from uneven wetting and the presence of folds in the clothing. Moreover, while the emissivity of skin may be taken as unity without error, a similar assumption for clothing is not valid. The effect of a low clothing emissivity on the measurement of T_e would be to underestimate $T_a - T_e$, both where the clothing temperature is above ambient (T_e as calculated would be too low) and where clothing temperature is below ambient (T_e as calculated would then be too high). If radiation exchange only were involved, the temperature error would be self-compensating inasmuch as the error could be considered as an apparent reduction in either emissivity or radiation area. However, a real error is incurred with convection exchange, since this must be related to the true temperature. The assumed clothing emissivity of 1 here used is probably not greatly in error. Crude measurements in this laboratory gave a value between 0.85 and 0.9 for the emissivity of dry HBT. Aldrich, quoted by Wulsin (7), gives the value of 0.81 as the emissivity of HBT at low temperatures (60°C.). These values suggest a possible error in $T_a - T_e$ of 10% to 20% and a corresponding error in $\frac{C + R}{\Delta T}$. In the 120°F. environment, the measured T_e would be high by 1 to 2°C. Since water has a high emissivity at these temperatures, and since the clothing was at least partially wet in all the experiments, the error may be even smaller.

RESULTS

Nude subjects: Evaporation. Under normal circumstances the sweat-regulating mechanism adjusts sweat output to a rate adequate to maintain thermal equilibrium. As the thermal stress increases, whether external or internal (metabolic), the sweating rate progressively increases until heat dissipation by evaporation compensates for the heat gain of the body. With increasing sweat rates or with decreasing evaporative capacity of the atmosphere (high vapor pressure, low wind velocity) the sweat output eventually becomes high enough

to completely wet the surface of the subject. When that condition is reached the rate of evaporation becomes a function of two factors, wind velocity and the difference in vapor pressure between the water on the skin and in the atmosphere. However, when the wetting of the surface is not complete, then the rate of sweat output, hence sweat evaporation, is determined by the imposed thermal stress, and the rate of evaporation per se is independent of environmental factors. Consequently, if one is to evaluate the influence of wind velocity and vapor-pressure difference on rate of evaporation, it is necessary to confine study to those conditions where the rate of evaporation is limited by the capacity of the atmosphere to take up moisture, i.e., to the completely wetted condition.

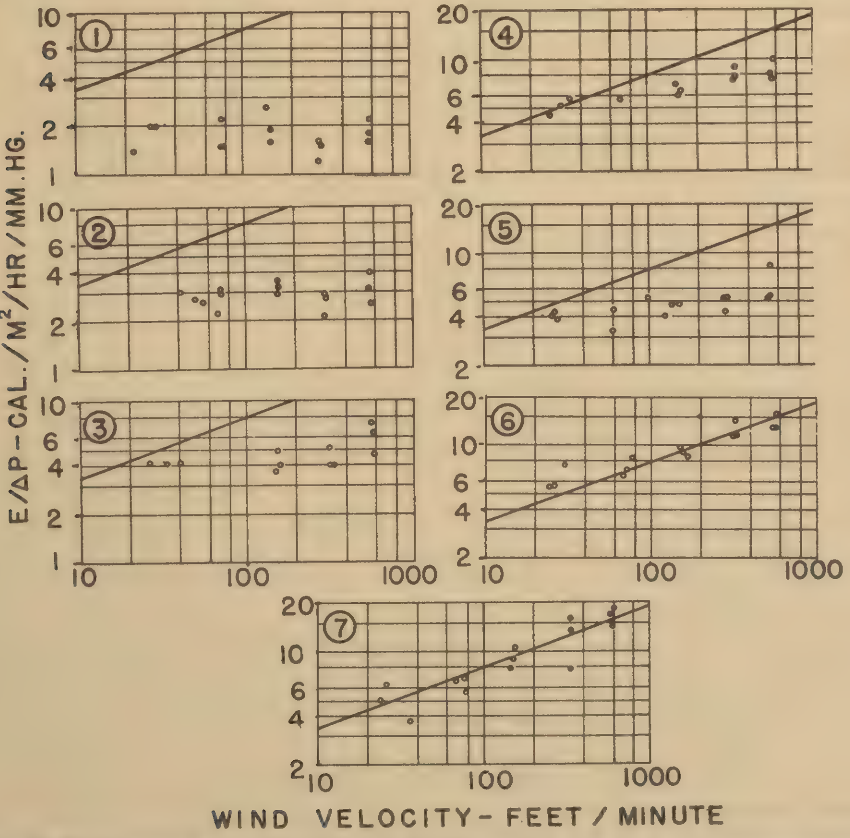
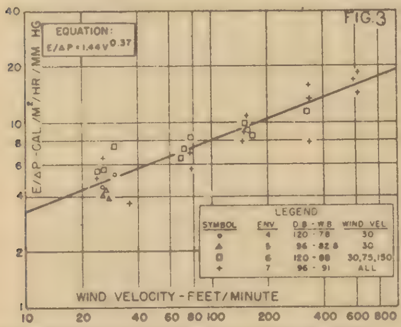
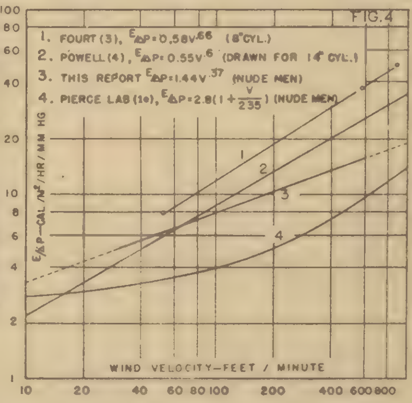


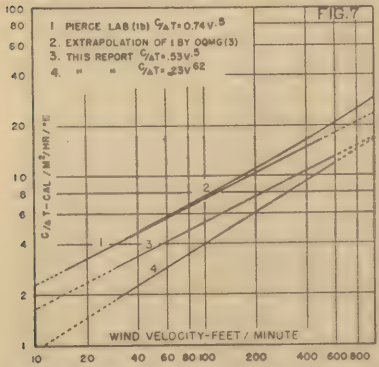
FIG. 2. EVAPORATION AS A FUNCTION OF WIND VELOCITY FOR NUDE STANDING SUBJECTS. **The circled numbers correspond to the environment numbers as given in table 1. The lines are drawn according to the equation $E/\Delta P = 1.44V^{0.37}$.**

The failure of wind velocity to influence the rate of evaporation at low sweating rates is shown in figure 2 in which the apparent coefficient of evaporation is plotted against wind velocity for the 7 environments studied. In the first two environments the rate of evaporation is independent of wind velocity. The

rate of evaporation begins to increase with wind velocity when environmental dry bulb temperature alone increases (increased sweat rate), as in environments 3 and 4, and when the evaporative capacity of the atmosphere decreases (increase in ambient vapor pressure), environment 5. Finally, with still greater reduction in the evaporative capacity of the atmosphere, environments 6 and 7, sweat is produced more rapidly than it can be evaporated, and the coefficients of evaporation increase decisively with increasing wind velocity reaching limiting values indicated by the lines in figure 2.







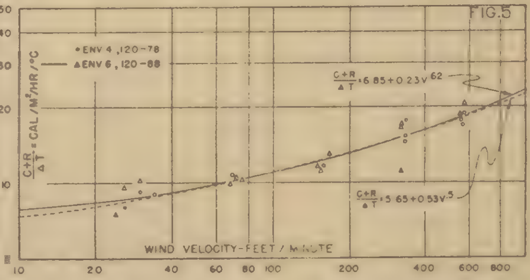


Fig. 3. Evaporation as a function of wind velocity for nude standing subjects To insure complete wetting only those experiments in which 10% or more of the sweat remained unevaporated are included.

Fig. 4. Comparison of various relationships that have been used to describe evaporation as a function of wind velocity.

Fig. 5. Coefficients of convection plus radiation plotted against wind velocity. Nude standing subjects.

Fig. 7. Comparison of various relationships that have been used to describe convection as a function of wind velocity.

By limiting consideration to those experiments where a high degree of wetting is present, data useful for characterizing the influence of wind velocity on evaporation can be obtained. An objective basis for selection is to include only those experiments where evaporation was less than 90% of the total sweat output, i.e., 10% or more of the sweat dripped from the man or remained on the skin. Data so selected are plotted in figure 3. These coefficients show reasonably good grouping and suggest an exponential relationship between the coefficient of

evaporation and wind velocity. A line fitted to the data by the method of least squares yields the equation $E/\Delta P = 1.44V^{0.37}$. The exponential relationship has precedent in the findings of Powell (4) on the rate of evaporation from cylinders, and has also been suggested on theoretical grounds (5). Studies of the influence of wind velocity on evaporation from completely wetted cylinders by Powell (4) and Fourt (quoted in 3) have indicated that the coefficient of evaporation varies approximately as $V^{0.6}$. In contrast, our results suggest that the coefficient is a function of $V^{0.4}$. The reasons for the difference are not clear. Two possibilities are suggested: 1) that in our experiments complete wetting of the skin was not maintained at the higher wind velocities; 2) that the human body, though often conveniently considered as consisting of a series of cylinders, differs sufficiently in its actual geometrical configuration to account for the difference.

In figure 4 the coefficients of evaporation obtained in this study are compared with those from the two studies on cylinders mentioned above and with an extrapolation used by the Pierce Laboratory (1d, e). The deviation of our results from those derived from the Pierce Laboratory equation is not surprising. This equation is an extrapolation by a questionable procedure and is based on a still air evaporation coefficient. However, the differences between our results on man and those of Powell and Fourt on cylinders will require further study and eventual explanation.

Convection and radiation. Figure 5 shows the coefficients for the combined $C + R$ calculated from the nude experiments in environments 4 and 6. The points are moderately well grouped and fall around a smooth curve. Since a certain amount of leeway is possible in fitting a curve to these points, a number of curves considered equally probable were drawn and analysed. If the assumptions are made that the convection coefficient is related to an exponential function of V and that the radiation coefficient is independent of V, the following equation is suggested:

$$\frac{C + R}{\Delta T} = (a + bV^c)$$

where a corresponds to the radiation coefficient. Differentiation of this expression suggests that plotting of $\log \frac{C + R}{\Delta T} \Big/ \Delta V$ against $\log V$ should give a straight line having a slope equal to $(c - 1)$ and an intercept equal to $\log bc$. Establishment of b and c permits calculation of a. Values of a can be calculated for each pair of $C + R$ and V values, and the results so obtained then averaged. Alternatively $C + R$ can be plotted against the appropriate function of V, and a line fitted by the method of least squares. This procedure, which fixes both a and b, is illustrated in figure 6A for $F(V) = V^{0.5}$. Treatment of the several curves in this way leads to a series of equations whose limiting values are expressed in the two equations

$$\frac{C + R}{\Delta T} = 6.85 + 0.23V^{0.62} \qquad (1)$$

and

$$\frac{C + R}{\Delta T} = 5.65 + 0.53V^{0.5}. \tag{2}$$

The equation describing convection as function of $V^{0.5}$ is tentatively favored for several reasons. The $\sqrt{V}$ relationship leads to a more acceptable value for $R/\Delta T$. The theoretical value of the coefficient, $\frac{R}{T_1 - T_2} = 4.92 \times 10^{-8}(T_1^4 - T_2^4)$ is 6.19 at the approximate temperatures of these experiments (37°C. and 48°C.). The value of 6.85 (equation 1) is thus too high even if the effective radiation area were equal to the man surface area. The coefficient of 5.65 (equation 2) gives in relation to the theoretical value of 6.19 a radiation area of 91%; this is reasonably close to the estimated value of 80%. In addition, equation 1 leads to lower values for $C/\Delta T$ at very low wind velocities than does the second equation. Comparison with data available on $C/\Delta T$ at such wind velocities (1d) favors the higher convection coefficient given by the $V^{0.5}$ relationship (equation 2).

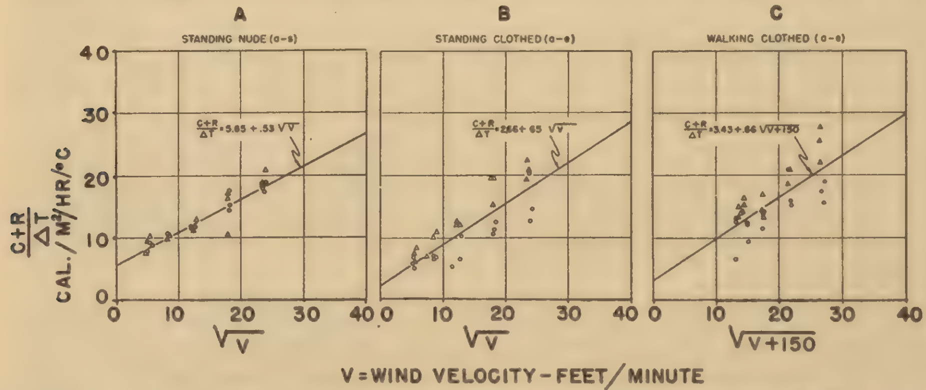


FIG. 6. CONVECTION PLUS RADIATION VERSUS WIND VELOCITY. Circles: 120°F, D. B., 78°F, W. B. Triangles: 120°F, D. B., 88°F, W. B. The coefficients are based on the temperature difference from air to skin (a − s) in the nude experiments and air to clothing (a − e) in the clothed experiments, and on actual skin surface area, not the clothed surface area.

Measurements of convective exchange with cylinders for a wide range of air temperatures, cylinder sizes and wind velocities (5) have been satisfactorily correlated with air movement by means of dimensionless ratios. These correlations favor the exponent of 0.6 for V for the range of wind velocities here studied. However, until data permit a more definite choice than is now possible, the $\sqrt{V}$ relationship seems more satisfactory.

The dimensionless ratio procedure has been used to extrapolate the Pierce Laboratory data to higher wind velocities (3).[10] Lines are drawn in figure 7

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[10] With this method of extrapolation the exponent of V increases with V, consequently curve 2 (fig. 7) leads to higher values than curve 1 at high wind velocities.

to represent the original Pierce Laboratory expression, the revised form as extrapolated and the two expressions suggested by the present study. The deviation of the Pierce Laboratory data from ours probably derives from the different experimental conditions employed. Their air movement was turbulent, secured by several fans in a small booth; in our studies the flow was linear.

No attempt has been made in this treatment to correct the convection coefficients for natural convection (chimney effect). It is probable that natural convection contributes significantly to the coefficients at low wind velocities; however, inadequacy both of the data and of the theoretical treatment of this problem (*see* McAdams, 5) makes such correction unprofitable at this time.

The expressions suggested here for thermal exchanges are presented only as a convenience in correlating the data and for use in interpolation. It would be foolhardy to use these equations to extrapolate beyond the conditions from which they were derived. Moreover their application to conditions where air flow is not linear may not be valid.

Clothed subjects: Evaporation. Evaporation from clothed subjects may proceed according to several different paths. In certain situations several patterns of evaporation may be occurring simultaneously at different points on the body. Three possible paths are illustrated in figure 1 B, C, and D. In an attempt to define a coefficient of evaporation, it is necessary to consider on what factors the coefficient depends. Whenever evaporation occurs from the surface of completely wet clothing, as in C or D, figure 1, the controlling factors are the same as those operative in the nude subject; namely, vapor pressure difference between surface and air and wind velocity. The situation changes, however, when as in B, figure 1, evaporation occurs from the skin and the water passes through the clothing as vapor. In this case the significant vapor-pressure difference is that from skin to air, not clothing to air. A new factor is introduced, the diffusion resistance offered to the vapor by the clothing barrier. Though wind velocity is still an influencing factor, its contribution is considerably reduced by the interposed diffusion resistance.

Though there is little reason to anticipate that the rate of evaporation from completely wetted clothing would differ significantly from the rate of evaporation from skin, several factors in the present data prevent the demonstration of this probability. After the initial warm-up period, the subject donned a fresh dry uniform and then entered the wind tunnel for the 30-minute test period. Consequently, even with the highest sweating rates, the clothing was dry during a portion of the test period. Therefore, in none of the clothed experiments was evaporation confined exclusively to the clothing surface; a portion of the evaporation must have occurred from the skin through the clothing.

The increased difficulties in assigning a mean temperature to the surface of a clothed, as compared to a nude, man have been described; these uncertainties influence the reliability of P_e(since P_e is based on T_e) and hence of $P_a - P_e$ and the evaporation coefficient, $E/\Delta P$.

An evaluation of the effective wind velocity on a man walking in a moving air

stream will be presented later. The data now to be considered have been plotted against the tunnel wind velocity.

Figures 8 and 10 indicate the effect of wind velocity on the coefficient of evaporation for standing clothed and walking clothed men in the 7 test environments.

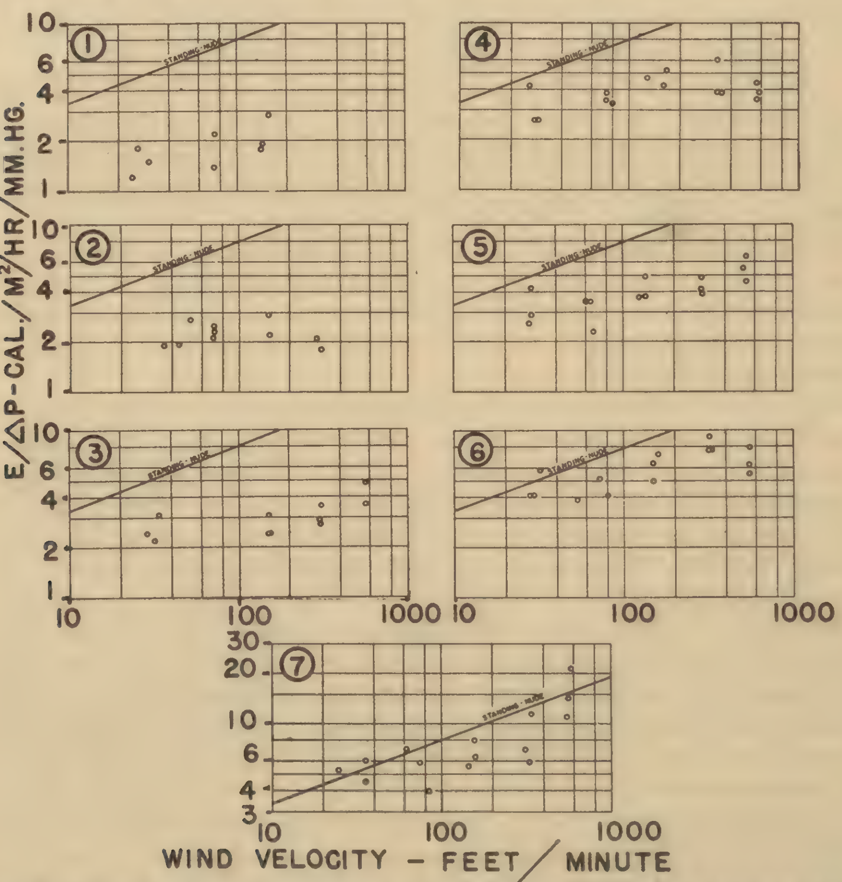


FIG. 8. EVAPORATION AS A FUNCTION OF WIND VELOCITY for clothed standing subjects. The circled numbers correspond to the environment numbers as given in table 1. The coefficients of evaporation are based on the vapor pressure gradient from clothing to air (a − e) and on the actual skin surface area of the subject, not the clothed surface area. Only those experiments are plotted in which 20% or more of the sweat remained unevaporated.

As in the nude subjects, the rate of evaporation is virtually independent of wind velocity at low sweat rates (less severe environments), but becomes progressively more dependent on wind velocity as the environmental severity increases. In the nude experiments maximal coefficients were approached when the data was restricted to those situations where less than 90% of the sweat was evaporated. For the clothed subjects (figures 8 and 10) even with a still more generous allowance for wetting (evaporation less than 80%, 20% or more unevaporated), a

progressive increase in the coefficient continues as the sweating rate increases and evaporative capacity of the environment decreases. This suggests that the allowance for wetting of the clothing is still inadequate. To test this possibility the data were separated into groups according to total sweat output (figures 9 and 11). This analysis shows a progressive increase in the coefficient of evaporation with increasing sweat rates, but there is little to suggest that maximal rates are being approached, except perhaps for *group* 4, figure 11, which includes the highest sweat rates.

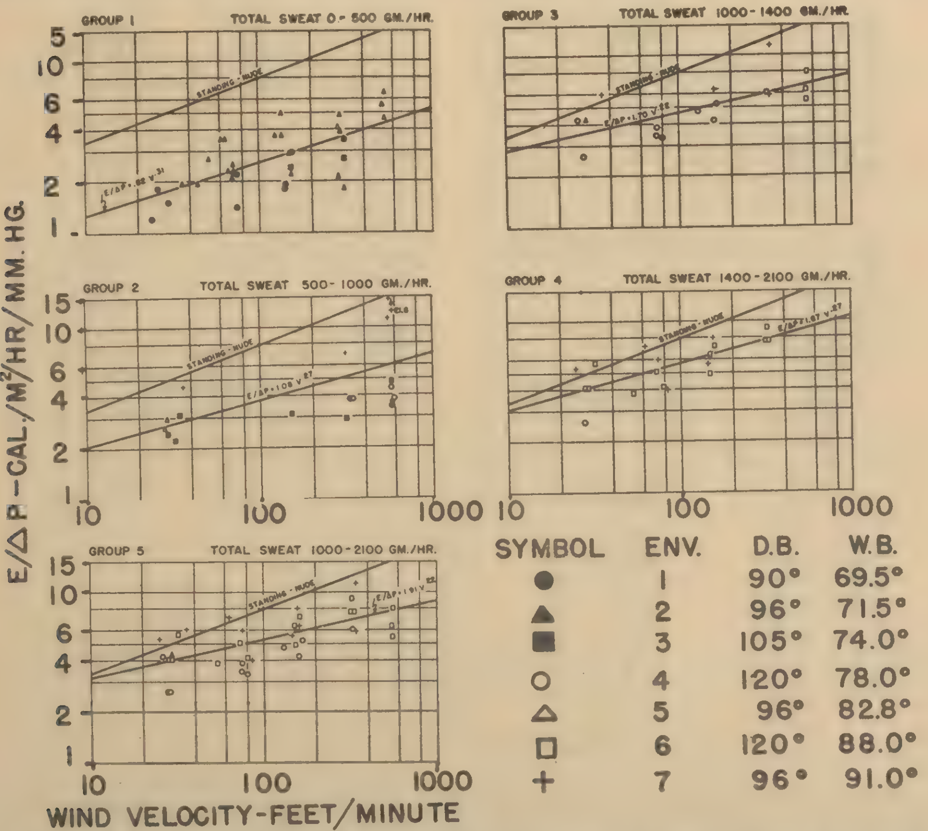


FIG. 9. EVAPORATION AS A FUNCTION OF WIND VELOCITY for clothed standing subjects. Data as in figure 8 grouped according to amount of total sweat.

In a further analysis of *group* 4, the tunnel wind velocity was corrected for the increased motion of the arms and legs by adding 150 feet/minute (explained in the next section) to all wind velocities, and the coefficients were corrected to a clothed surface area, using a factor of 1.3. These corrections permit comparison of the coefficients for clothed men directly with the coefficients determined on nude subjects (fig. 12). Since most of the points fall below the values for the nude subjects, incomplete wetting of the clothed surface occurred in even the

most favorable situation, indicating that in none of the clothed experiments have maximal surface coefficients of evaporation been reached.

The 20% allowance of unevaporated sweat is probably more than adequate to ensure complete wetting of the skin. Hence it seems likely that the measured rates of evaporation under such conditions can be considered as maximal coefficients, not for completely wetted clothing, but for partially wetted clothing where the evaporation occurs to varying degrees through several paths: *a*) from wet skin through the dry clothing, *b*) from the surface of wet clothing.

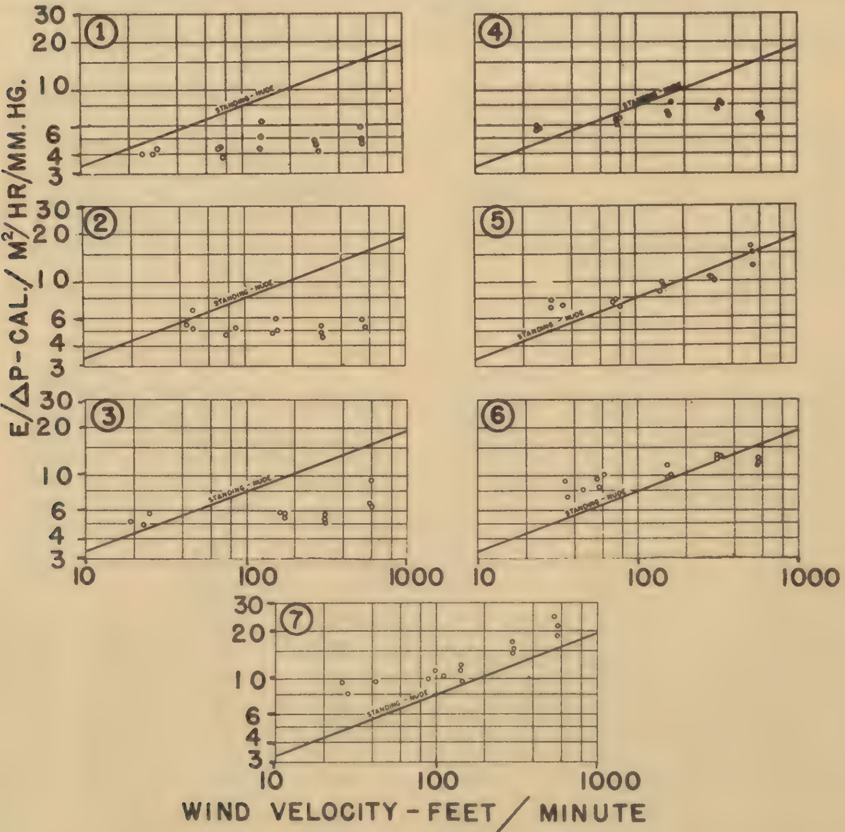
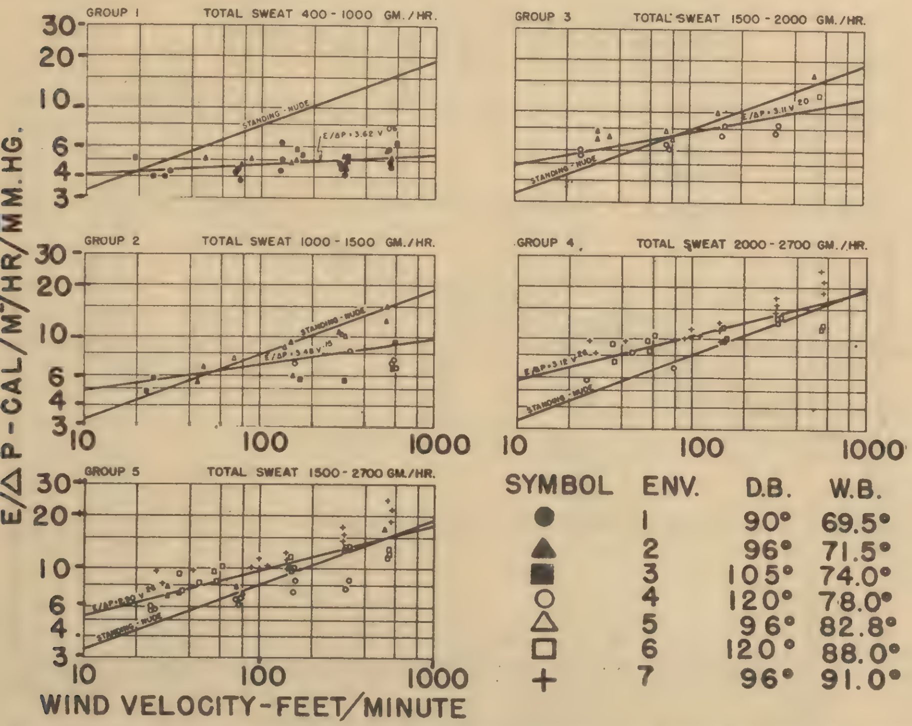


FIG. 10. EVAPORATION AS A FUNCTION OF WIND VELOCITY for clothed walking subjects. The circled numbers correspond to the environment numbers as given in table 1. The coefficients of evaporation are based on the vapor pressure gradient from clothing to air (a − e) and on the actual skin surface area of the subject, not the clothed surface area. Only those experiments are plotted in which 20% or more of the sweat remained unevaporated.

The situation is a complex one and is not susceptible to simple analysis or presentation in a form likely to be generally useful. The presentation given in figures 9 and 11 may be useful for some purposes. It should be noted, however, that the coefficients are calculated on the gradient from the clothing surface

to air. This is not the significant gradient for evaporation from the skin through dry clothing. Data are available on the influence of fabric porosity on the evaporation coefficient (Fourt, 3). However, they are of little help in the absence of a basis for determining the proportion of evaporation that occurs from the skin through clothing. Lacking such information, the most useful purpose of the present data is to give gross coefficients of evaporation for a range of sweat rates.



SYMBOL	ENV.	D.B.	W.B.
●	1	90°	69.5°
▲	2	96°	71.5°
■	3	105°	74.0°
○	4	120°	78.0°
△	5	96°	82.8°
□	6	120°	88.0°
+	7	96°	91.0°

Fig. 11. Evaporation as a function of wind velocity for clothed walking subjects. Data as in figure 10 grouped according to amount of total sweat.

Convection and radiation. The effective wind velocity increase resulting from the arm and leg motion of walking has been estimated by direct comparison of the coefficients of evaporaton and convection of standing and walking men (fig. 13). The chart shows $\frac{C + R}{\Delta T}$ for the 120°F. environments 4 and 6 and $E/\Delta P$ for those experiments where the total sweat output was between 1400 and 2100 grams/hour. The abscissal differences between the curves drawn through the points are given in table 5 and suggest that the effective wind velocity for a walking man is increased by 80 to 200 ft/min. above the measured air velocity in the tunnel. The intermediate value of 150 ft/min. is used below (also fig. 12) to correct the measured wind velocity in the walking experiments. Where this is done the symbol V' is used, where $V' = V + 150$.

The procedure used for separating C from R in the clothed experiments is based on the assumption that $C/\Delta T$ is functionally related to wind velocity in the same way in the clothed tests as in the nude ones. To this end the values of $\frac{C+R}{\Delta T}$ are plotted against $\sqrt{V}$ in figure 6 B and C. Lines fitted to the points by the method of least squares give the equations

$$\text{Standing clothed, } \frac{C+R}{\Delta T} = 2.66 + 0.65\sqrt{V}$$

$$\text{Walking clothed, } \frac{C+R}{\Delta T} = 3.43 + 0.66\sqrt{V'}.$$

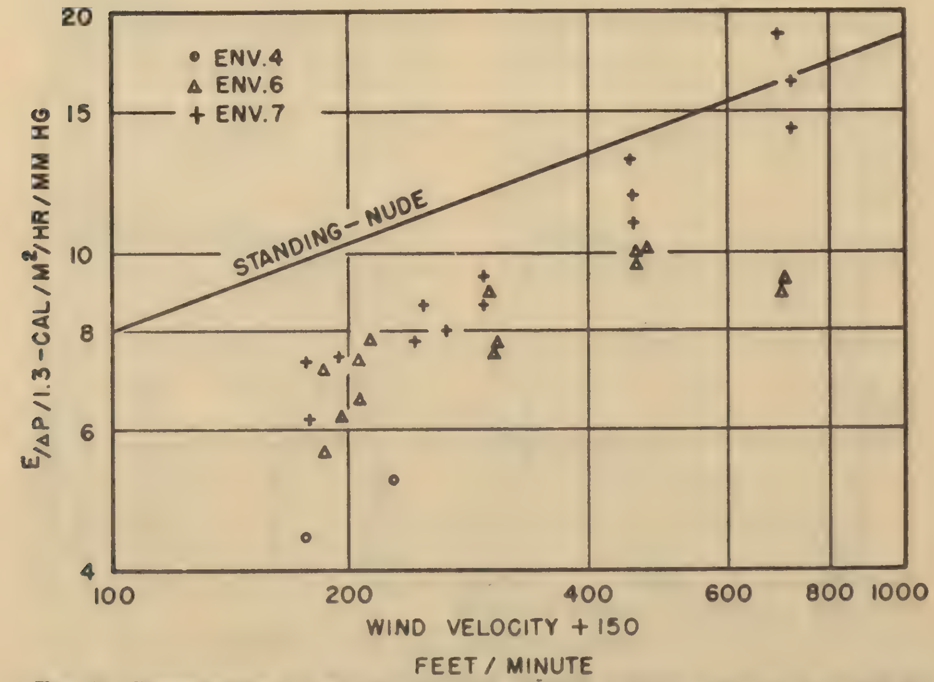


FIG. 12. COEFFICIENTS OF EVAPORATION for clothed walking subjects corrected for clothing surface area and for the apparent increase in wind velocity due to walking. Includes only those experiments in which sweat rates ranged between 2000 and 2700 grams/hr.

Consider first the coefficients of R. Since the walking man has a larger effective radiation area than the standing man, the values 2.66 and 3.43 qualitatively bear the correct relationship to each other. Quantitatively their ratio of 0.79 is somewhat lower than would have been expected on the basis of estimated radiation areas of 80% and 90% for the two conditions, respectively.

The absolute values of these radiation coefficients are much lower than anticipated and no reasonable explanation has been found for the discrepancy. Due to the larger surface area of the clothed subject, the $\frac{R}{\Delta T}$ for the clothed man

should be 20% to 30% higher than for the nude man unless the clothing emissivity is low. This possibility appears to be ruled out by the data available on the emissivity of the clothing worn.

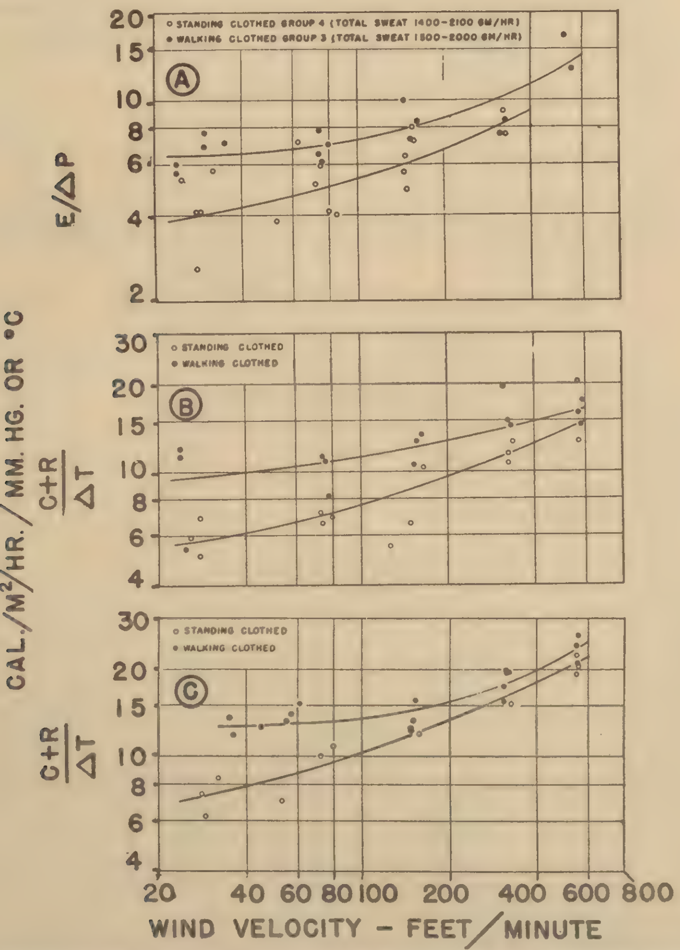


FIG. 13. ILLUSTRATION OF THE METHOD used to estimate the influence of walking on the apparent wind velocity. Smooth curves are drawn through the points from the standing clothed experiments (open circles) and walking clothed experiments (closed circles). The abscissal displacements are listed in table 5. A, presents evaporation coefficients for standing and walking experiments where the total sweat rates are in the same range. B and C show similar comparisons of convection plus radiation coefficients for environments 4 and 6, respectively.

The convection coefficients $C/\Delta T = 0.65\sqrt{V}$ and $0.66\sqrt{V'}$ are in good agreement. Their ratios to the corresponding value (0.53) for the nude subjects are 1.23 and 1.24 which are perfectly compatible with the anticipated increase in surface area of the clothed men.

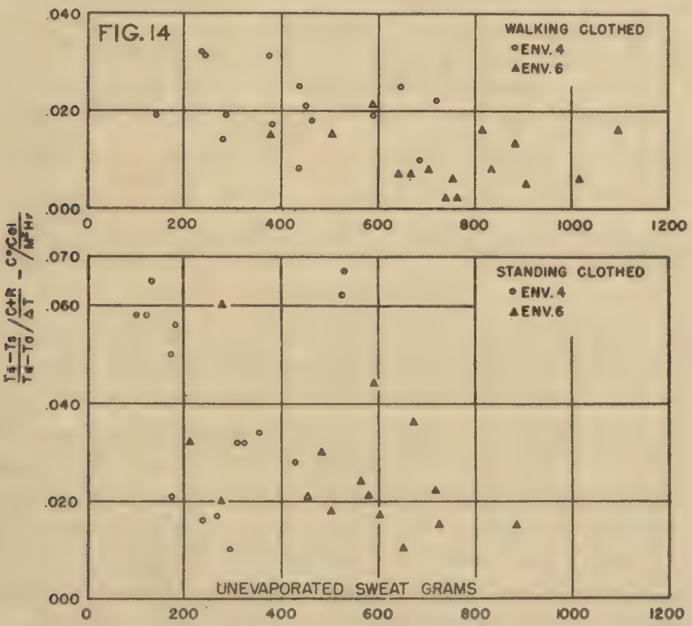
Nevertheless, the total $\frac{C + R}{\Delta T}$ is lower than can be explained. The question may therefore be raised, whether the satisfactory values for $C/\Delta T$ may not be fortuitous and whether the net deficit of $C + R$ should be distributed between both the convection and radiation coefficients, making both coefficients too low. Since the possible error in measurement of $T_a - T_e$ from assuming too high a value for clothing emissivity tends to underestimate $T_a - T_e$, $\frac{C + R}{\Delta T}$ would be still lower if the correct $T_a - T_e$ were used. Thus, though $\frac{C + R}{\Delta T}$ as calculated is low, the full extent of this deficit may have been concealed by dividing by a too small ΔT.

TABLE 5. *Apparent increase in wind velocity with walking*

	WIND VELOCITY ft./min.		
	Standing Clothed	Walking Clothed	Δ
E/ΔP 1400 to 2100 gms/hr			
cals M² Hr			
8	300	145	155
7	215	80	135
6.5	180	40	140
$\frac{C + R}{\Delta T}$ Env. 4			
15	610	420	190
12	360	150	210
10	225	45	180
$\frac{C + R}{\Delta T}$ Env. 6			
22	580	480	100
15	260	180	80
13	190	50	140

From a practical standpoint, convection or radiation to clothed men is most satisfactorily defined in terms of the effective insulation of the clothing. However, the evidence that E can vary according to the path of evaporation independently of clothing insulation indicates that difficulty may be expected in characterizing clothing insulation from the data available. This is further shown by equations B, C and D of figure 1, where $\frac{T_s - T_e}{T_e - T_a}$ is related to the various insulation coefficients and to M and E. In the simplest situation, 6B, the clothing insulation $I_c + I_i$ is equal to $I_a \frac{T_s - T_e}{T_e - T_a}$ and in this case $I_c + I_i$ can be calculated.

When, however, evaporation deviates from this route as in C and D, $I_a \frac{T_s - T_e}{T_e - T_a}$ is no longer a simple function of the clothing insulation.



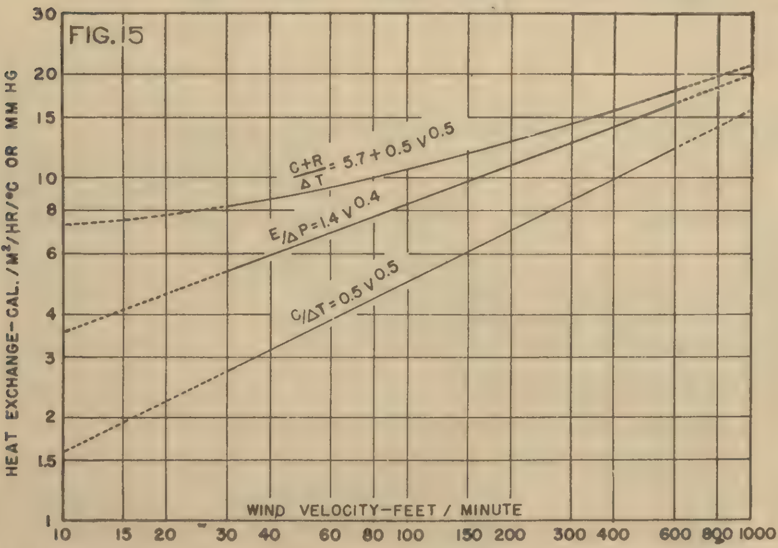


FIG. 14. APPARENT CLOTHING INSULATION IN RELATION TO UNEVAPORATED SWEAT.

FIG. 15. ROUNDED VALUES OF COEFFICIENTS OF CONVECTION, RADIATION AND EVAPORATION, NUDE SUBJECTS.

Recognizing this, but in an effort to cast some light on the effect of clothing wetness on its insulation, $I_a \frac{T_s - T_e}{T_e - T_a} \left(\text{or } \frac{1}{K_a} \frac{T_s - T_e}{T_e - T_a} \right)$ has been plotted against

unevaporated sweat in figure 14. The result, as anticipated, suggests that with increasing wetness of clothing its conductance increases.

Two factors suggest that the apparent insulation as plotted in figure 14 may be reasonably valid: First, in condition C (fig. 1) the value plotted, $\frac{1}{K_a}\frac{T_s - T_e}{T_e - T_a}$ should differ only slightly from the true clothing insulation, $I_i + I_c$, since the coefficient of E in the denominator of equation 6C can be expected to be very close to one. Second, condition D, fig. 1, requires that T_e be lower than T_s. In the condition here treated, where T_a is higher than T_e, a negative ratio, $\frac{T_s - T_e}{T_e - T_a}$ would result if condition D dominated. The absence of negative values in figure 14 suggests that evaporation according to path D is relatively minor.

DISCUSSION

The results of the analysis of the experiments with nude subjects appear fruitful. The coefficients of the three exchange paths studied, convection, radiation and evaporation, are all consistent with expectations and with the limited data available for comparison. The data for evaporation has no counterpart; the only reasonable comparison is with the data of Powell and Fourt (4, 3). The differences revealed by this comparison are perhaps not larger than would be anticipated, taking into account the scatter of our results and the inherent differences in the type of experiment. Further study is desirable on many grounds, but especially needed is an answer to the possible criticism that incomplete wetting was present in our experiments at the higher wind velocities.

The independent estimation of the radiation coefficients yields a satisfying confirmation of earlier work. As more information accumulates over extended ranges of conditions, the adequacy of the theoretical description of radiation exchange as applied to nude men becomes more apparent.

As with radiation, the descriptions here offered for convection exchange in nude men fall largely into the category of extension of available information to different conditions of air flow and to more severe environmental conditions. The most useful information on convection exchange at high wind velocities will probably come from study of linear air flow which occurs much more frequently at high wind velocities than does turbulent flow.

For practical use, the following rounded values are suggested for the coefficients derived from the nude experiments:

Evaporation, $E/\Delta P = 1.4V^{0.4}$

Convection, $C/\Delta T = 0.5V^{0.5}$

Radiation + convection (120°F.), $\frac{C + R}{\Delta T} = 5.7 + 0.5V^{0.5}$.

In these equations thermal exchange has the units Cal/M^2/hr/°C. or mm.Hg, and air velocity is expressed as feet/minute. Lines drawn from these equations are shown in figure 15.

The results from the experiments with the clothed subjects are perhaps most useful insofar as they point out the complexity of the problem and the difficulties likely to be encountered in applying the method of partial calorimetry. Most of the uncertainties of the present analysis would be eliminated if a complete heat balance were available. The evaporation coefficients require complete restudy under conditions insuring better control and greater uniformity of wetting, a difficult but very practical and important task.

The data presented here on the gross coefficients of evaporation for clothed men are of very limited usefulness, but until better information is available, they may serve to fix the order of magnitude of evaporation from partially wet clothing.

With respect to the convection and radiation coefficients from the clothed men, two alternatives are offered. The easiest course at the moment is to disregard the results on the basis of inadequate definition of the surface temperature, or measurement of storage, or both. On the other hand, if we are to accept the eminently reasonable values found for $C/\Delta T$ we are forced into the necessity of accepting what at present appears to be an unacceptable value for clothing emissivity.

SUMMARY

1. Coefficients of thermal exchange for nude men standing and for clothed men, standing and walking, have been estimated by partial calorimetry in 7 environments and at 5 wind velocities. Dry bulb temperatures ranged from 90°F. to 120°F; vapor pressures, 13 to 36 mm.Hg; wind velocities, 30 to 600 ft/minute.

2. In nude subjects the maximum coefficient of evaporation can be described by the equation $E/\Delta P = 1.4V^{0.4}$.

3. Sweating rates adequate to measure the maximum coefficients of surface evaporation in clothed men probably were not reached. Charts presenting the coefficients actually found are shown.

4. Coefficients of convection for nude men can be described by the equation $C/\Delta T = 0.5\sqrt{V}$.

5. Estimates of the convection coefficient for clothed subjects gave values 23% and 24% higher than the coefficient found for nude subjects. This is consonant with estimates of the ratio of the surface area of clothed to nude men.

6. The coefficient of radiation for nude subjects was 5.7 Cal/M^2/hr/°C. This value is in agreement with a theoretical coefficient based on emissivities of wall and skin of 1 and a radiation area equal to 91% of the surface area.

7. The coefficients of radiation for clothed subjects were much lower than would be predicted from reasonable assumptions as to emissivity of the clothing surface. No explanation of this discrepancy is offered.

8. Movement of the arms and legs while walking resulted in an increase in the apparent wind velocity. This amounts to approximately 150 ft/min. over the tunnel air flow when subjects walk at a 3 m.p.h. pace.

The Influence of Cold Upon the Efficiency of Man

By Steven M. Horvath and Arthur Freedman
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THE LOSS in efficiency due to exposure to cold has not been very clearly defined by field observers. The common impression appears to be that the performance of specified tasks requires the service of more man-hours, the commonly stated ratio varying from two to four times that required to do the job under temperate environmental conditions. Comprehensive time studies have not been made. Such problems cannot be adequately studied in the laboratory. However, related problems, such as hand strength and finger dexterity are capable of analysis and solution. The hands and their adequate protection are of prime importance to a soldier, since they must be used continually and efficiently in the handling and repair of weapons and personal equipment.

METHODS

During the past year considerable information has been obtained in an attempt to clarify these problems. These studies were conducted at —10° to —14° F. and at —20° F. with zero wind velocity. The last temperature was selected because it was considered to be the lowest temperature at which both the personnel and the vehicular equipment of the Armored Command would be able to function without the occurrence of serious breakdowns. Observations were made during two types of cold exposure:

1. Long term—up to fourteen days of continuous residence in the cold room.
2. Short term—acute exposures of three hours' duration.

The tests employed in these studies were:

1. Simple Visual Discrimination Reaction Time
2. Johnson Code Test
3. The gear assembly test devised at the laboratory
4. Hand Grip Test—dynamometer

Twenty-two men who lived in the cold chamber for periods of eight to fourteen days were subjects for one group of experiments. These men were exercised outdoors for twelve days and then were brought into the air-conditioned laboratory (temperature 72° F., relative humidity 50 per cent). After four days in this environment they entered the cold room, temperature —20° F., and remained there continuously for from eight to fourteen days. After arising from their sleeping bags, their daily routine consisted of the following: psychomotor tests, breakfast, a one-hour walk at 2.5 miles per hour, a period of quiet sitting for two hours followed by lunch. After lunch there was an hour's walk also at 2.5 miles per hour, a half hour of heavy work, another hour's walk, psycho-

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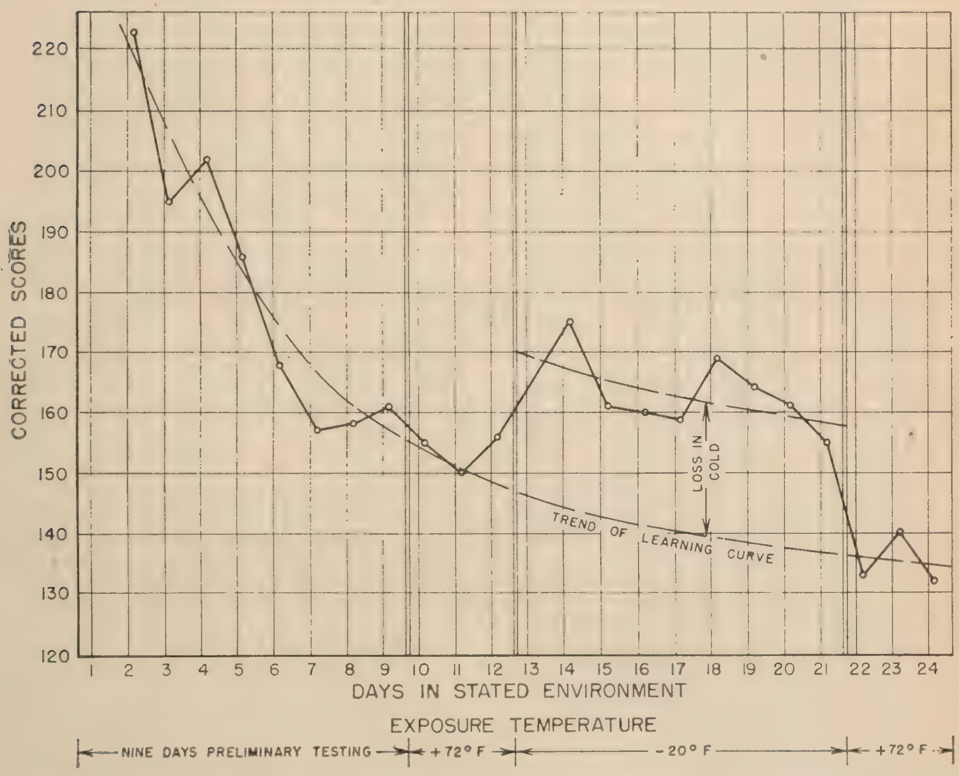

Fig. 1. Average scores on the Johnson Code Test during successive continuous exposures to constant environmental conditions.

motor tests and then supper. The evenings were free periods with entertainment in the form of motion pictures. Partial escape from the cold was possible by the provision of a small hut in the cold chamber, the temperature of which was above zero but below freezing. The men usually retired early in the evening to their sleeping bags. These men wore the six-piece arctic assembly with mukluks and felt boots (Alcan type). The handwear used was the M-1943 mitten combination.

The acute exposures consisted of periods of three hours at temperatures of approximately —10° to —14° F. Seventy men (fifty white and twenty negro) were used in these tests, the only psychomotor test made on them being the grip strength test. These men were dressed exactly alike (Arctic Zone Issue M-1943) and were exposed to the cold on three successive mornings.

RESULTS AND DISCUSSION

Johnson Code Test.—This test is presumed to measure responses at a cortical level. However, since the test requires the use of a pencil to write down single letters of the alphabet, the test had for our purposes additional value as a measure of finger dexterity.

An initial period of instruction and practice was given to each man prior to the first experimental session, in order to familiarize him with the tests and to advance his performance beyond the stage of rapid learning. The extremely long learning curve which was found to occur with this test was a handicap. Although the Johnson Code Test was performed with and without mittens (wool, trigger finger) the results presented are only those when the mitten was worn. Two tests were given at each session. The data are presented in terms of corrected scores, the time required to perform the test adjusted for the errors made. In this test, the poorer performer has the higher score.

Since the individual curves had the same general configuration, an average curve is presented in Figure 1. The men appeared to reach an equilibrium state in their scores just prior to entering the cool environment and remained close to this level during their stay at +72° F. Their performance was markedly inhibited by an environment of —20° F. The influence of cold on ability to perform the Johnson Code Test is apparently masked by an uncompleted learning curve as is evident from the tests made in the follow-up period at a cool environment (+72° F.) which revealed continuing improvement in accordance with the trend line.

There is immediately a question as to which of the two factors acting in this test, cortical activity or finger dexterity, are primarily affected by the cold. Since there was no increase in the number of errors made by the men, the possibility that cortical activity may be impaired appears to be ruled out. It is probable, therefore, that the influence of cold is most evident in loss of finger dexterity. The abilities to approximate the fingers and to flex and straighten the basal joints are presumably affected by exposure to cold. The movements requiring the apposition of the thumb and fingers are concerned in many grasping and manipulative movements; activities such as writing, buttoning coats, working radio knobs, et cetera, become difficult in cold environments.

Gear Test.—Ten of the twenty-two subjects were tested on the time required to disassemble and reassemble a Peep differential ring gear assembly. The subjects wore wool mittens and were required to use a hammer and an open-end wrench, in addition to the hands, for this manipulative test. Eight recessed nuts and bolts held the assembly together. A period of time for practice was again allotted the subjects to get them beyond the learning stage before actual testing began.

In general the results of this test were similar to those found for the Johnson Code Test. The poorest performances were observed when the test was performed in the cold. In the cold environment, the average performance for the two best men was increased from approximately two and a half minutes in the cool temperature to four minutes in the cold. Like all tests of this type there was a considerable difference in the amount of deterioration that occurred; the best subjects showed the smallest degree of change, and the poorest the greatest change.

Simple Visual Discrimination Reaction Time.—The discriminative reaction time, two choices, was measured by a one-hundredth-second standard electric time clock, the lighting of one of two neon tubes being used for the stimulus. This test was used as a measure of speed and precision. Each subject was given fifty trials, and the average of all trials was used to indicate his performance. This test, while easy to give, also has a long learning period and is not readily applicable to studies of short duration. Minor inattentiveness can also produce considerable variation in performance.

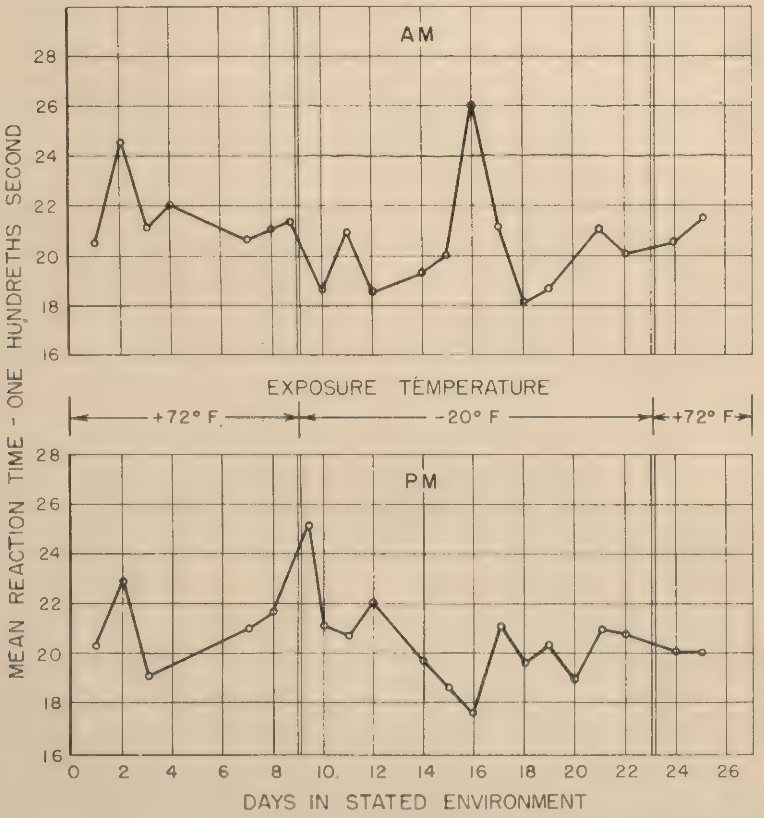

Fig. 2. Simple visual discriminative reaction time of a subject at + 72° F. and − 20° F.

Figure 2 illustrates the typical responses observed in all of the subjects tested. The early portion of the learning curve is omitted. No alteration in reaction time was detected either during the exposure to the cold or as an after-effect of cold exposure. In ten of the twenty-two men given this test, there was a sharp decrease in response on the first evening test in the cold environment. Following this initial lower response, the reaction times returned

to their former values and exhibited only minor fluctuations thereafter. In general it appears that cold has no influence on speed, precision, nor reaction to visual stimuli as measured by this test.

Tests were made not only at the beginning and the end of a day's work but also during the day immediately following a bout of exercise. No effects due to fatigue were observed.

TABLE I. THE INFLUENCE OF EXPOSURE TO COLD ON THE GRIP STRENGTH OF WHITE AND NEGRO SOLDIERS

Day of Exposure	Per Cent Loss of Grip Pressure			
	White		Negro	
	Right Hand	Left Hand	Right Hand	Left Hand
1	31.5	28.4	29.0	30.3
2	28.6	27.7	30.1	27.0
3	26.9	30.0	27.1	24.2
Average	29.0	28.7	28.7	27.2

TABLE II. GRIP STRENGTH OF WHITE AND NEGRO SOLDIERS AT A COMFORTABLE AMBIENT TEMPERATURE

	Grip Strength in Kilograms			
	White		Negro	
	Without Mittens	With Mittens	Without Mittens	With Mittens
Mean	51	44	55	46
Range (maximum)	37-71	25-68	33-85	30-72

Grip Pressure (Hand Strength).—It was possible to make a study of the grip pressure exerted by seventy subjects on each of three successive days of exposure to the cold. These men sat quietly for three hours each morning in the cold room at an ambient temperature of —10° to —14° F. They were dressed in similar clothing and all wore the same glove combination, viz., mitten, trigger finger insert, wool M-1943 and mitten, shell, trigger finger M-1943. Each man's grip was measured prior to entering the cold room and again immediately preceding his exit after three hours of quiet sitting. The outer shell mitten was removed and the hand strength measured with the wool mitten on the hand. A hand dynamometer, calibrated in kilograms, was used to measure the hand strength.

The average grip pressure exerted by the men was approximately 53 kilograms. This was decreased to some 45 kilograms when the mittens were worn (Table II). The subjects showed wide variability in hand strength. After the men had sat for three hours at —10° to —14° F. there was an average decrease in grip strength of about 28 per cent (Table I). There was no difference between the white and negro soldiers. The negro groups were in the cold for only two and one-half hours

instead of three hours required of the white soldiers. The frequency distribution of the alterations in hand pressure for all subjects is shown in Figure 4. It is evident that there is a wide distribution in the extent of weakening which occurred. For some unexplained reason hand strength was not diminished in approximately 2 per cent of the trials.

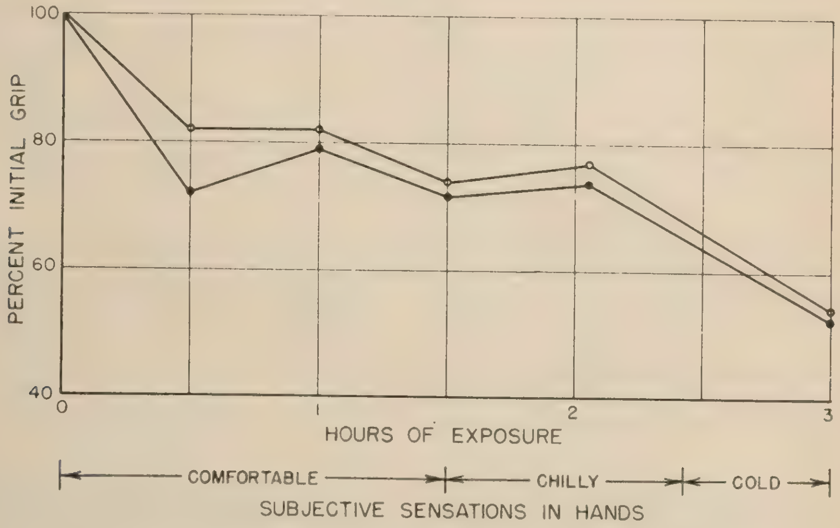

Fig. 3. Changes in exerted pressure (hand grip) in a subject during exposure to —10° to —14° F. Open circles indicate right hand, and solid circles indicate left hand. Initial value, 47 kilograms, equals 100 per cent.

At the time that the men squeezed the dynamometer, just before leaving the cold room, 65 per cent of them reported their hands to be "painfully cold," 27 per cent had hands that were just "cold" and 8 per cent had hands that were only "chilly." However, most of this last group had reported their hands to be cold with varying degrees of pain sometime during the previous hour and a half. No correlation was found between the subjective report of the severity of pain experienced in the hands and the extent to which grip pressure had decreased.

The loss in hand strength became apparent quickly in some of our subjects. Figure 3 illustrates the behavior of one of these men. At the end of the first half hour a decrease of about 20 per cent was observed, although the subject's hands were still "comfortable." Even when he reported his hands to be only cold, he had a diminution in strength of approximately 50 per cent. When control observations were made at the same time intervals at a comfortable ambient temperature (+72° F.), only minor variations were found in the pressure exerted.

These data present a picture of the interference with strength and dexterity when men are exposed to cold environments. In general, interference is greater for the man with the smaller

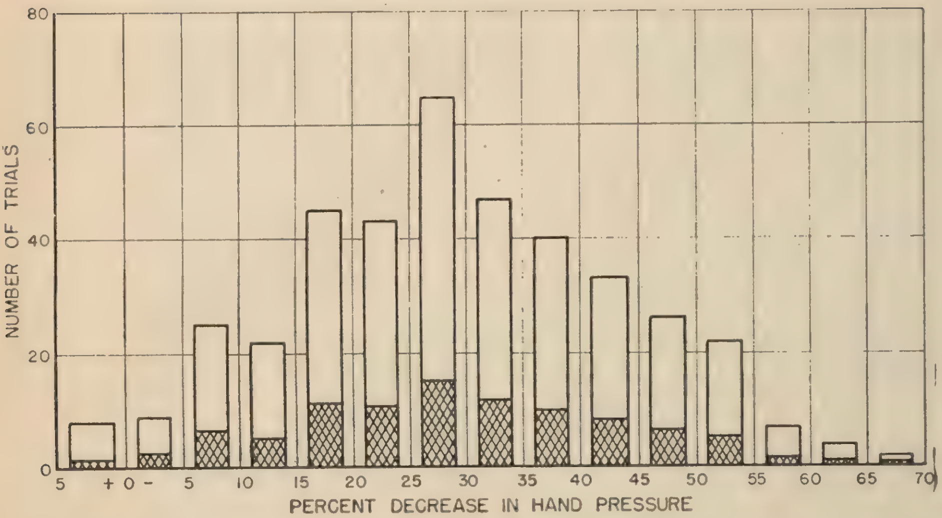

Fig. 4. Changes in exerted pressure (hand grip) of seventy subjects following exposure to —10° to —14° F., while sitting for three hours. Open columns indicate white subjects, while cross-hatched columns indicate negro subjects.

grip strength and least for the man with the greater grip strength. It is also shown that the best glove combination available does not provide adequate insulation to permit men to maintain their hands at their optimum efficiency. Any loss in strength or dexterity is of extreme importance to armored personnel. For example, nuts and bolts tightened in a warm environment could not be loosened by a cold hand nor tightened sufficiently to prevent a mechanical breakdown. The loss in hand strength and finger dexterity in cold environments indicates the need for extreme care in the design of equipment for cold weather operations.

CONCLUSIONS

1. The reaction time to visual stimuli was not altered during continuous exposure to a low environmental temperature for periods of eight to fourteen days.

2. Dexterity of the fingers and hand strength was markedly diminished by exposure to low ambient temperatures even when the duration of such exposure was for a relatively short period of time.

ACCLIMATIZATION TO EXTREME COLD

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From the Armored Medical Research Laboratory, Fort Knox, Kentucky

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ACCLIMATIZATION TO EXTREME COLD

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The only unequivocal evidences of acclimatization to environmental conditions differing radically from normal temperate environments are those reported to occur in hot environments (4, 5, 12, 14). Data on the process of acclimatization to cold are lacking, although Bazett and his co-workers (1, 2, 16) have demonstrated slow adaptations to cool environments. A most remarkable example of adaptation to an ambient of approximately 0°C. has been shown to occur in the Australian aboriginal (6). Not only does he exhibit a greater lability toward vasoconstriction but also his heat production on exposure to cold remains at a constant level. On the other hand, according to Hill and Campbell (7), children receiving cold open-air treatment have elevated basal metabolic rates. Eskimos also exhibit BMR's from 14 to 21 per cent above normal standards (3). Animals have increased metabolic rates during and immediately after a period of continuous exposure to cold (11, 13, 15).

Most of these observations were made at relatively warm environments, freezing and above, and consequently do not provide the answer as to whether acclimatization occurs in the very extreme ambient temperatures observed in arctic and sub-arctic regions. Arctic explorers differ widely in their opinions both as to the occurrence and the rate of development of acclimatization.

In previous reports, Horvath and co-workers (9, 10) discussed the effects of short intermittent exposures to environments as low as −47°C. on the functioning of the heat regulating apparatus of men who either sat quietly or worked at a standard rate. Due to the nature of the observations, it was not possible to obtain evidence for or against the development of acclimatization to low temperatures. The data to be presented in this paper are concerned primarily with the reactions of men to an eight day period of continuous exposure to an ambient temperature of −29°C.

METHODS. A group of ten healthy young soldiers[4] were trained for twelve days outdoors in the July heat of Fort Knox, Kentucky. Their training consisted of walking a distance of 12 miles daily at a speed of 3.0 mph. Additional walks on the treadmill were also made daily. After this preliminary period, they were brought into the cold chamber described in another report (9) and remained there for three days in an envirionment of 25°C., R. H. 50 per cent. The chamber was then cooled to −29°C. Six of the ten men remained in

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[4] Average age, 21.5 years; height, 68 inches; weight, 155 pounds; and surface area, 1.83 square meters.

the cold room continuously day and night for eight days, while the remaining four slept in their barracks at night, but entered the cold chamber before breakfast each morning and remained there until after sundown each evening. They engaged in practically the same activities as the six men who resided continuously at −29°C. In the cold room the men wore the six piece Arctic Suit[5] M-1942, which has an insulative value of 3 to 4 Clo. Their daily activities for the three days previous to cooling the chamber, for the eight days at −29°C., and for the three days following the cessation of their low temperature exposure consisted of this set pattern: One hour's walk at 3.0 mph. after breakfast, then two hours of quiet sitting followed by lunch; after lunch, an hour's walk, a half hour's heavy work period, another hour's walk, a period of quiet sitting for 40 minutes, a series of psychological tests, and then dinner. There was some entertainment in the form of radio and reading during the day and motion pictures in the evening. Partial escape from the cold was permitted in the evening by the provision of a small hut in the cold chamber (temperature −5 to 0°C.). However, the men usually retired into their sleeping bags early in the evening.

TABLE 1

SUBJECT	AGE	HEIGHT	WEIGHT	SURFACE AREA (M^2)
		cm.	*kg.*	
FO	19	182	76.6	1.98
CU	20	175	70.6	1.85
RE	20	172	65.8	1.76
MO	19	165	56.6	1.64
BE	27	178	68.7	2.00

The results of studies on fluid balance, blood, and psychological responses (8) will be reported in later publications. The present paper is based primarily on observations of the sitting and working metabolism of five of the ten subjects. Only one of these five men was a member of the group which spent a portion of its time outside the cold room. The physical characteristics of these subjects are given in table 1. The procedures employed in this investigation were similar to those previously described (9, 10). The sitting metabolism of subject BE was obtained with a closed circuit apparatus and consequently for two hours he breathed air which was at a temperature of +20°C. For all the other sitting subjects the temperature of the inspired air was −29°C., the expired air being collected for ten minutes in Douglas bags. Analyses of aliquots of the collected air were made in duplicate on Haldane machines. Skin temperature data were incomplete, since the correct techniques for preventing breakage of the copper

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[5] This consisted of two sets of ⅜ inch pile trousers, two sets of ⅜ inch pile parkas and a white cotton camouflaged outer suit. The inner pile suit was worn with pile towards the skin, while the pile of the outer suit faced the camouflaged garment. Two pairs of heavy wool socks were worn inside mukluks. Hand protection was provided by a pair of wool gloves and outer shell mittens (M-1943).

constantan thermocouples had not been fully developed. However, some data on toe temperatures were adequate and will be discussed. Rectal temperatures were obtained by means of calibrated clinical thermometers.

RESULTS AND DISCUSSION. The average rectal temperature of the five subjects throughout the day (measurements made on arising, after first work period, after rest period, after each of three afternoon work periods, and prior to retirement) was approximately 37.8°C. during the entire eight days at low environmental conditions. This was very similar to values obtained during the preliminary and the post-exposure periods. No significant changes were noted in the basal rectal temperatures secured while the subjects were still in their sleeping bags. Variations were noted in each subject but were not consistent. Basal values as low as 35.2°C. were found in a number of cases. The rate of fall of rectal temperatures during the sitting periods did not differ appreciably on any of the eight days. During the last third of the sitting period of the third day, there was observed a large fall in the rectal temperatures of all subjects, but its cause was not determined. Since adequate consecutive data on mean skin temperature were not obtained, changes in mean body temperature could not be estimated. In the few subjects on whom chest and thigh temperatures were successfully secured on all days at the low ambient temperatures, no changes attributable to duration of exposure were found.

The basal heart rate was not altered during the period of cold exposure. The mean values on the second day of cold were 56, on the fifth day, 55, and on the eighth day, 58. The heart rates during the sitting periods (table 2) were variable and might be explained as due to increased muscle tone or slight shivering by some of the subjects.

The mean oxygen consumption (open circuit method), during the two hours that four subjects sat quietly (fig. 1), showed an increase of approximately 30 per cent over control values at +25°C. Detailed data secured at three points during each two hour sitting period are given in table 1. No consistent pattern was exhibited during the eight days of exposure. While in general all subjects showed a trend to remain at an elevated level during the exposure to cold, two roughly similar groupings were noted in the daily variations of caloric expenditure. Nothing in the past experiences or the physical characteristics of the subjects could be correlated with these patterns.

After returning to a comfortable environment, the subjects' oxygen consumption decreased but was still higher than the pre-cold control values. This stimulating effect of cold exposure confirmed the results of animal experiments conducted by Horvath et al. (12).

It is of interest to compare the metabolic rates obtained on two subjects similarly exposed (fig. 2) when one of them, BE, breathed warm air while the other, FO, breathed cold air (−29°C.). Neither of these two subjects reported gross shivering, although they undoubtedly had some increased muscular tone. The increased metabolism was seen initially in both subjects, but after the first three days BE's heat production began to decrease, and in the last few days it was only slightly elevated. This response would be considered a classic example

of acclimatization to cold except that it was not noted for any of the four subjects who were breathing cold air. The after-stimulating effect of cold on metabolism was not observed to occur in subject BE. It is of special note that, while all the subjects reported they did not mind the cold so much after the first few days, only BE stated that he was definitely more comfortable. Whether he was the only subject to be acclimated or whether the breathing of warm air was the deciding factor was not then determined. Some experiments performed later failed to demonstrate any beneficial effects of breathing warm air during short periodic exposures to low environmental temperatures.

TABLE 2

The mean metabolic values obtained on four subjects who sat for a period of two hours each day during continuous exposure to the designated environmental temperatures

	ENVIRONMENTAL TEMP. °C										
	25.0°C.	−29.0°C.							25.0°C.		
		Days of exposure									
		1	2	3	4	5	6	8	9	10	11
At 40 minutes											
R.Q.	0.86	0.83	0.86	0.86	0.83	0.75	0.85	0.88	0.82	0.79	0.83
Ventilation L./min.	8.2	10.5	9.9	9.6	9.4	11.0	10.3	10.7	9.2	8.3	8.3
Oxy. cons. ml./min.	354	482	472	451	427	493	461	501	378	368	378
Cal./hr.	173	233	230	220	206	236	224	245	183	176	183
Rectal temp. °C	37.2	37.0	37.3	37.4		36.7	37.0	36.5	36.6	36.7	36.9
Heart rate/min.	60	62	68	74	74	78	66	69	81	75	74
At 80 minutes											
R.Q.	0.89	0.88	0.82	1.04	0.86	0.90	0.86	0.85	0.94	0.92	0.80
Ventilation L./min.	7.5	8.5	8.0	8.4	9.0	12.0	9.4	9.8	9.5	9.9	8.2
Oxy. cons. ml./min.	307	358	368	316	381	503	374	416	303	309	324
Cal./hr.	150	175	178	161	186	247	182	202	151	153	156
Rectal temp. °C	36.7	37.1	37.2	37.1	36.9	37.1	36.9	36.6	36.9	36.8	37.0
Heart rate/min.	74	72	78	72	78	80	63	70	81	70	78
At 120 minutes											
R.Q.	0.88	0.82	0.81	0.88	0.85	0.86	0.83	0.92	0.82	0.80	0.82
Ventilation L./min.	7.4	9.4	9.2	9.5	9.7	10.2	9.4	9.6	8.5	7.9	7.8
Oxy. cons. ml./min.	300	400	426	419	442	455	424	420	354	330	332
Cal./hr.	136	193	204	210	215	222	205	208	171	158	160
Rectal temp. °C	36.9	36.9	36.9	36.3	36.8	36.9	36.8	36.7	36.9	36.6	36.9
Heart rate/min.	66	64	61	65	59	75	72	73	74	76	70

The toe temperatures obtained on BE and FO are of considerable interest (figs. 3a and 3b). They show the changes that occurred during the three hour morning periods (8 to 11 o'clock). Their toe temperatures were quite low from awakening through breakfast, but the walk raised them to fairly high levels. During the subsequent two hours of cooling, seated subject FO (fig. 3b) exhibited a strikingly similar pattern on all days, his final temperatures reaching the neighborhood of 10°C., similar to his pre-exercise levels. On the other hand, BE's toe temperatures presented definite evidence of an acclimatization effect

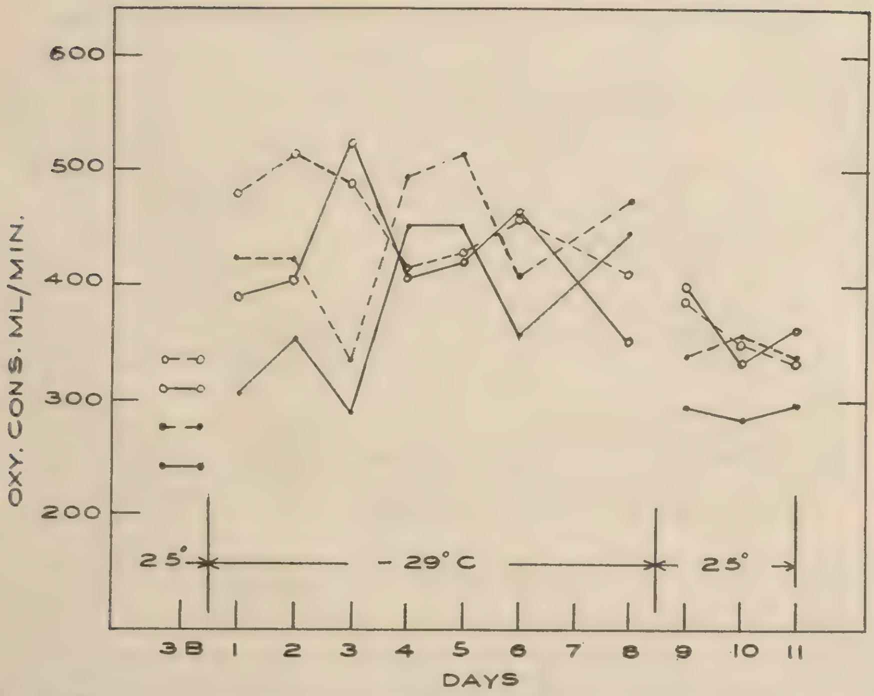

Fig. 1. The average oxygen consumption of four seated subjects during a two hour period in comfortable and cold environments.

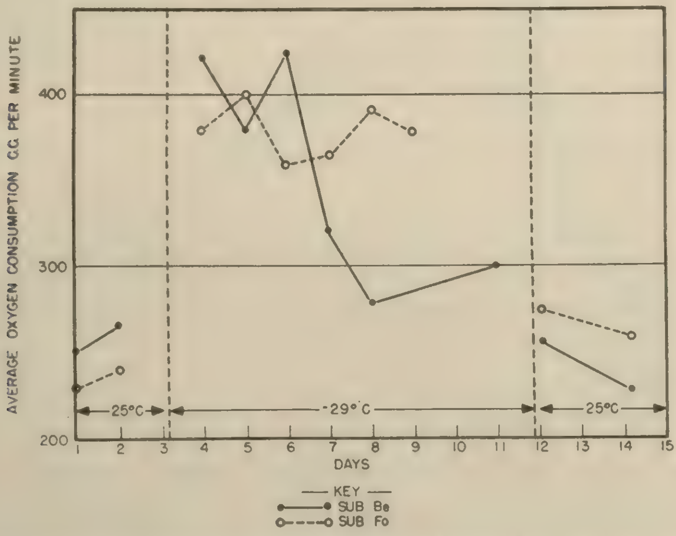

Fig. 2. Average oxygen consumption of two subjects sitting for two hour periods while residing continuously at the designated ambient temperatures.

in that the extremities not only warmed up more rapidly and to a greater degree on the last days of cold exposure, but also cooled at a definitely slower rate. [illegible]

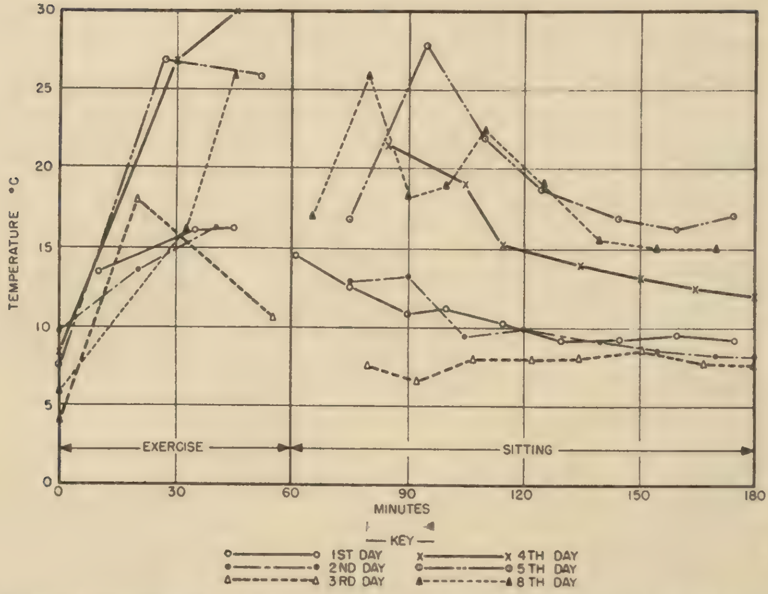

Fig. 3a. Toe temperatures of subject BE (one of the two subjects of fig. 2) during the morning hours of a period of continuous residence at a low environmental temperature.

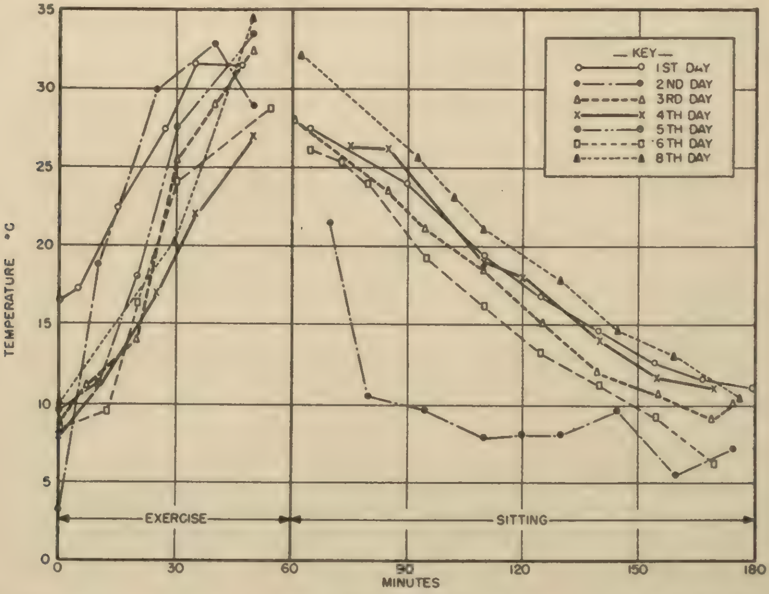

Fig. 3b. Toe temperatures of subject FO (one of the two subjects of fig. 2) during the morning hours of a period of continuous residence at a low environmental temperature.

There was a positive correlation between the higher final toe temperature and the mean caloric production during this cooling-off period. When his extremities

were cold, his metabolic rate was elevated and vice versa. If BE had been our only subject, definite evidence of acclimatization, in the usual interpretation of the word, again would be said to have occurred. However, his response was atypical in view of the reactions of the other subjects, and the breathing of warmer air may have altered his responses to some extent.

Metabolic observations were made on four subjects performing a standard amount of work at 25° and −29°C. Unfortunately, a follow-up period at 25°C. was not possible due to our having only one treadmill. Average data on four subjects are presented in table 3, with a graphic presentation in figure 4 of the findings on subject CU. As previously reported (10), exposure to low environmental temperatures was accompanied by an increased energy expenditure for the performance of a standard amount of work. The 25 per cent average rise in caloric output was slightly, but not significantly, higher in this group of subjects than in the group exposed for only a single hour to a similar ambient temperature (10). The energy expenditure during work decreased with continued exposure to the low ambient temperature. Although no regular pattern was evident in this increased efficiency of performance, viz., a return to cool environmental levels, the values obtained on the last two days were the lowest ones observed in the cold. Thus, continued exposure appeared to have a definite effect on physiological functions in that stimulation due to cold was less evident toward the end of exposure. This effect was not noted in all of the subjects (fig. 4). Except for his second day at −29°C., CU showed only minor changes in caloric output, which was partially a reflection of the slight rise in R.Q. observed in this subject.

TABLE 3

Metabolic observations on four (4) men, dressed in Arctic clothing and walking on a treadmill at 3.0 MPH and a 3.3 per cent grade while exposed to an environmental temperature of −29.0°C. continuously for eight (8) days

ENVIRONMENTAL TEMPERATURE	VENTILATION		RESPIRATORY QUOTIENT		OXYGEN CONSUMPTION		HEAT PRODUCTION	
	L./min	Δ%		Δ%	L./min	Δ%	Cal/hr	Δ%
+25.0°C.	26.7		0.92		1.22		360	
Days at −29.0°C.								
First	33.2	24.3	0.86	−6.5	1.65	35.2	483	34.2
Second	31.1	16.5	0.87	−5.4	1.50	23.0	440	22.2
Third	30.9	15.7	0.88	−4.4	1.54	26.2	452	25.6
Fourth	32.4	21.3	0.90	−2.2	1.51	23.8	448	24.4
Fifth	32.6	22.1	0.86	−6.5	1.59	30.3	464	28.9
Sixth	31.3	17.2	0.89	−3.3	1.46	19.7	430	19.4
Eighth	29.8	11.6	0.86	−6.5	1.50	23.0	438	21.7
Average*..........	31.6	18.4	0.87	−5.0	1.54	25.9	451	25.2

* For days at −29.0°C.

The average oxygen consumption of the four subjects appeared to have reached

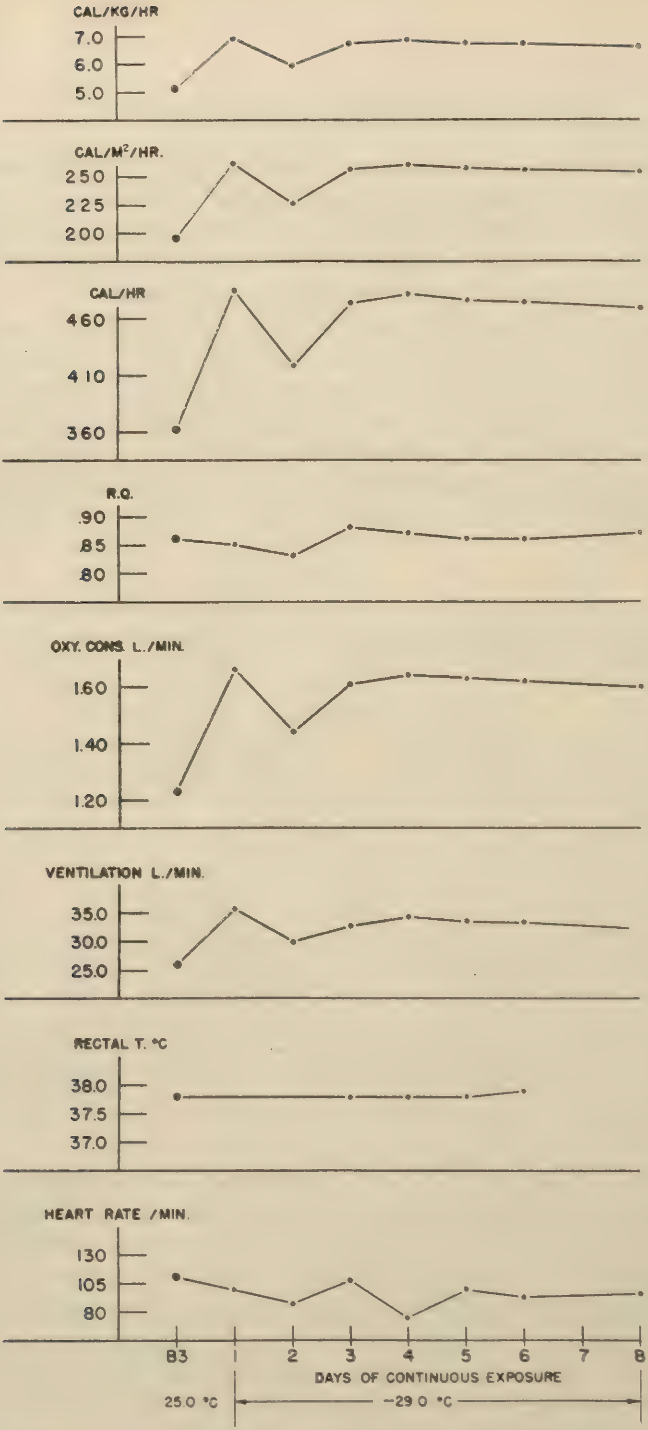

Fig. 4. Observations made on subject CU during a one hour walk (a.m.) on a treadmill at a speed of 3.0 mph and a 3.3 per cent grade before and during an eight day period of continuous residence in an environment of −29°C.

a fairly steady level after the first day in the low ambient temperature, the greatest variations being observed on the fifth and sixth days. The fall in R.Q. from the control days averaged about 5 per cent and showed minor variations during the succeeding days in the cold. The maximal fall occurred on the first day and, although it varied from day to day in the cold, it did not approach the pre-cold day values. Subject CU (fig. 4) again differed from the other subjects in that his R.Q. figures were generally higher during cold exposure than in the comfortable environment.

The ventilation rates at all times were greater at −29°C. than at 25°C. This increase, an average of 18.4 per cent, was accomplished through increased depth of breathing, as the respiratory rate was not affected. The smallest increase, approximately 12 per cent, was observed on the last day of the test. The greatest change was noted on the first day in the cold. Lower values, but not in a definite progression, were found on all succeeding days.

As illustrated in figure 4, the rectal temperature at the completion of the work period remained relatively constant during the successive days of cool and cold exposure. It is unfortunate that the constant breakage of thermocouples prevented collection of adequate data on the changes in body surface temperatures. The thigh temperatures obtained appeared to be higher on the last days than on the first days of cold exposure. The heart rate slowly decreased, the average fall being 12 beats. This may be in part a reflection of training.

Although the cost to the individual to do a given amount of work in the cold was always greater, a slight diminishing of this greater energy expenditure appeared to occur with longer periods of consecutive exposure to the low ambient temperature. This was reflected primarily in reduction of the total caloric output and the lowering of the minute ventilation volume.

Only one of the quietly sitting subjects exhibited measurable improvement in his ability to tolerate cold. All of the other men had variable responses and none of the changes in the physiological measurements could be attributed directly to length of exposure. It is possible that the duration of exposure was too short and that changes similar to those seen in subject BE may have occurred if the exposure to the cold had been continued.

There are indications that men do become acclimated to cold and that certain physiological mechanisms are involved in this process. Unfortunately, the individual variations are so great that no clearly delineated statement of the mechanism can be given at this time.

SUMMARY

Metabolic observations were made on five subjects who resided continuously for three days in a comfortable environment, 25°C., for eight days in a cold environment, −29°C., and for another three day period at 25°C. No changes in basal values for heart rate or rectal temperature occurred. The caloric expenditures during quiet sitting and while performing a standard amount of work were higher during exposure to the low ambient temperature. The duration of exposure to low temperatures did not markedly influence the energy output during the sitting period for four of the five subjects. The fifth individual, who

was breathing air of approximately 20°C. during this time, showed a striking decrease in caloric output with increased exposure. The significance of this finding and its association with a higher level of toe temperature has been discussed. Four of the subjects exhibited an increased metabolic rate—an afterstimulating effect of cold—on their return to the control environment. This was not observed in the fifth subject, the individual mentioned above.

The energy requirements for the standard work on a treadmill at 3.0 mph and a 3.3 per cent grade were increased during low temperature exposure. A small but definite return towards normal values occurred with continued exposure, but its relation to the development of a state of acclimatization was not clear. The decrease could be explained adequately on the participation of a number of other factors.

There is some indication from the data accumulated in this study that acclimatization to cold may occur, but at the present the evidence is too equivocal for a definite statement.

Acknowledgment. The authors wish to express their appreciation of the excellent co-operation of the enlisted men who voluntarily served as subjects and to Mr. James Gregg, M/Sgt. Walter Kupchick, T/Sgt. H. Bloom, and Mrs. Steven M. Horvath, for their assistance in conducting the experiments and the analysis of the data.

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CARDIAC ASYSTOLE IN A NORMAL YOUNG MAN FOLLOWING PHYSICAL EFFORT

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CARDIAC ASYSTOLE IN A NORMAL YOUNG MAN FOLLOWING PHYSICAL EFFORT

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ARMY OF THE UNITED STATES

THIS is the report of a cardiac asystole of nineteen seconds which occurred in a normal young soldier during a syncopal attack induced by physiologic means. Bradycardia during syncope is a common observation, and very low heart rates have been observed during syncopal attacks induced by various causes.[1-11] However, prolonged asystole during syncope is uncommon except in subjects with certain types of heart diseases or with carotid sinus sensitivity. In the present case syncope and asystole occurred while the subject was in the erect posture following a bout of hard physical work. Severe physical exertion has been shown to be frequently followed by an orthostatic hypotension[12-15] which may be so severe that syncope results.

The Harvard Pack Test[16] was used as the exercise procedure. The subject, stripped to shorts, socks, and shoes, and carrying a pack weighing one-third of his body weight, steps up and down on a platform sixteen inches high once every two seconds for five minutes. This work rate is of such severity that approximately one-third of normal young men fail to complete the required five minutes of effort. On stopping work, the subject sits down and, at intervals over the ensuing five minutes, the heart rate is counted. From these a fitness score is determined.

Following the five-minute sitting period, the subject in this study was placed on a tilt table which was used to change his posture alternately from 70 degrees erect to supine. While erect, the body weight was supported by the legs and no measures were taken to prevent postural sway, other than admonitions to stand still. Except when the erect periods were shortened by syncope, each position was maintained for five minutes during which the heart rate, blood pressure, respiratory rate, and electrocardiogram were repeatedly determined.

CASE REPORT

A white man, 22 years of age, weighing 165 pounds, and 5 feet, 8 inches in height, had completed basic training and for the preceding four months had engaged largely in clerical duties.

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Though somewhat overweight, his performance on fitness tests indicated an average physical fitness. The heart was not examined in detail but was assumed to be normal on the basis of good heart sounds without murmurs, a normal electrocardiogram, and the fact that he had passed several medical examinations without incident and had performed the physical tasks of military basic training without difficulty.

On Oct. 19, 1942, he performed the Harvard Pack Test, became exhausted after four minutes and ten seconds, and developed orthostatic hypotension with syncope in the postexertional standing periods. On Oct. 29, 1942, he performed the test for the second time. He had had a mild common cold for four days but felt quite well. After two minutes and thirty seconds of effort, he was stopped because he began to lag behind the required pace of one step-up per two seconds.

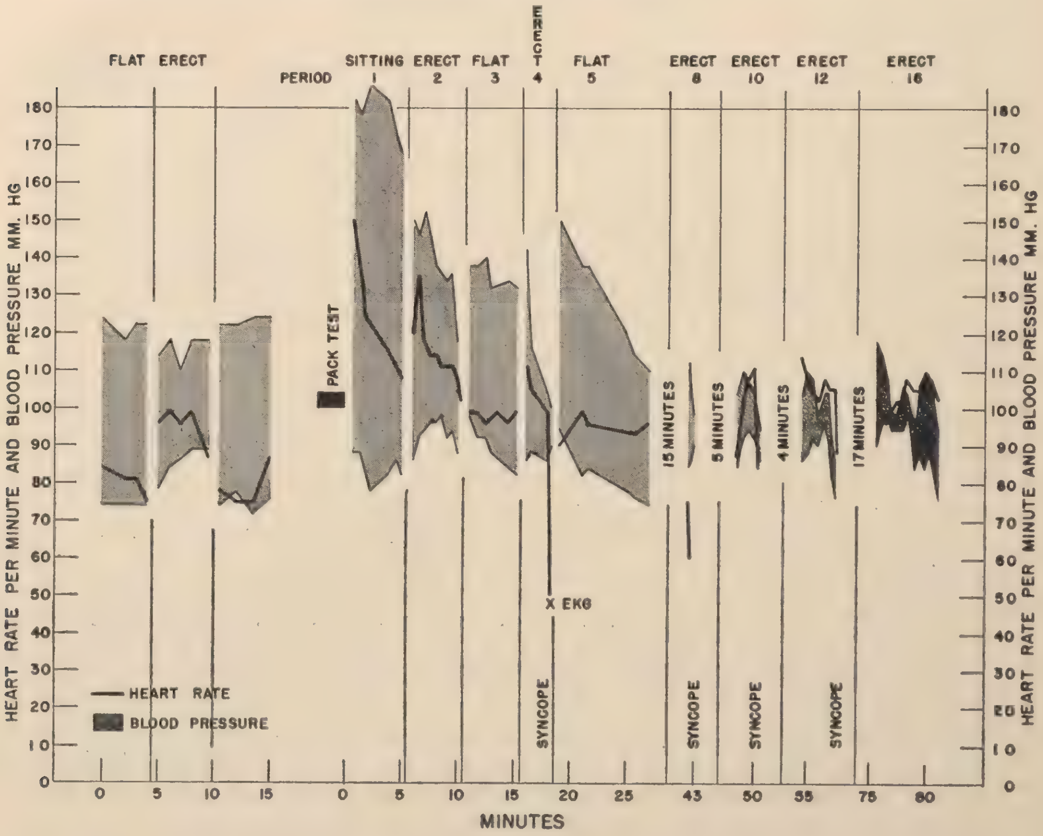

Fig. 1.—Response of blood pressure and heart rate to change of posture before and after severe physical effort (Harvard Pack Test). Heavy dark line, heart rate; shaded area, blood pressure. After Period 5, only the erect periods are plotted. Each of these was preceded and followed by a supine period in which the blood pressure and heart rate were similar to those at the end of Period 5.

Some of the circulatory changes induced by this second test are shown in Fig. 1. The elevated systolic blood pressure and rapid heart rate immediately after exercise (Period 1) are the usual results of physical work. Both the elevated blood pressure and heart rate subsided toward control values during the first erect period (Period 2) which was maintained for the required five minutes without discomfort. The breathlessness and distressing symptoms induced by the work had already disappeared. During the second erect period (Period 4) the systolic blood pressure

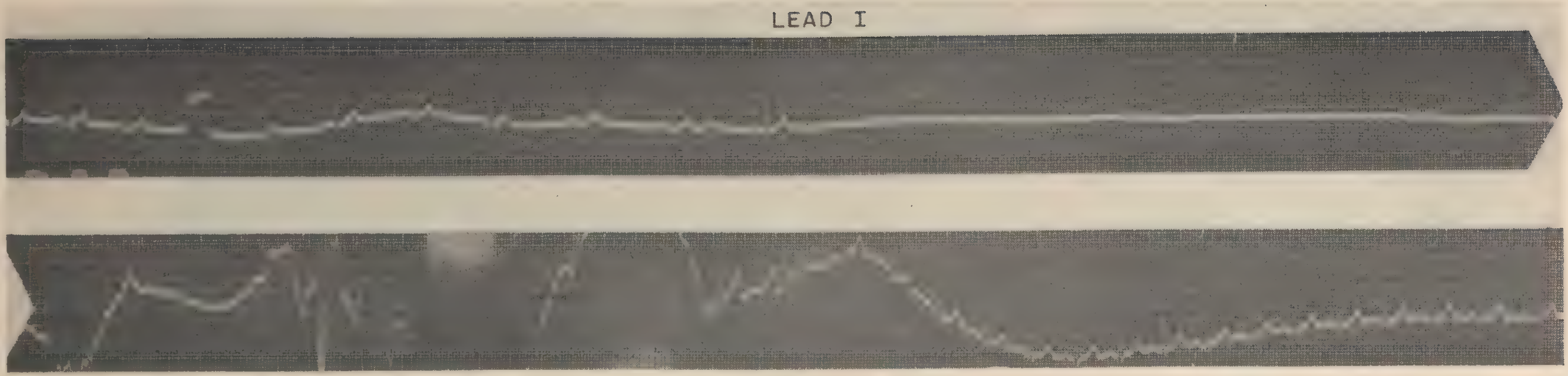

Fig. 2.—Electrocardiogram (Lead I) taken in the erect posture eighteen minutes after stopping work and at the time of collapse. The two strips form a continuous tracing; the lower one follows the upper one without a break in time. The apparent "wave" following the T wave of the next to the last complex in the upper strip is unexplained.

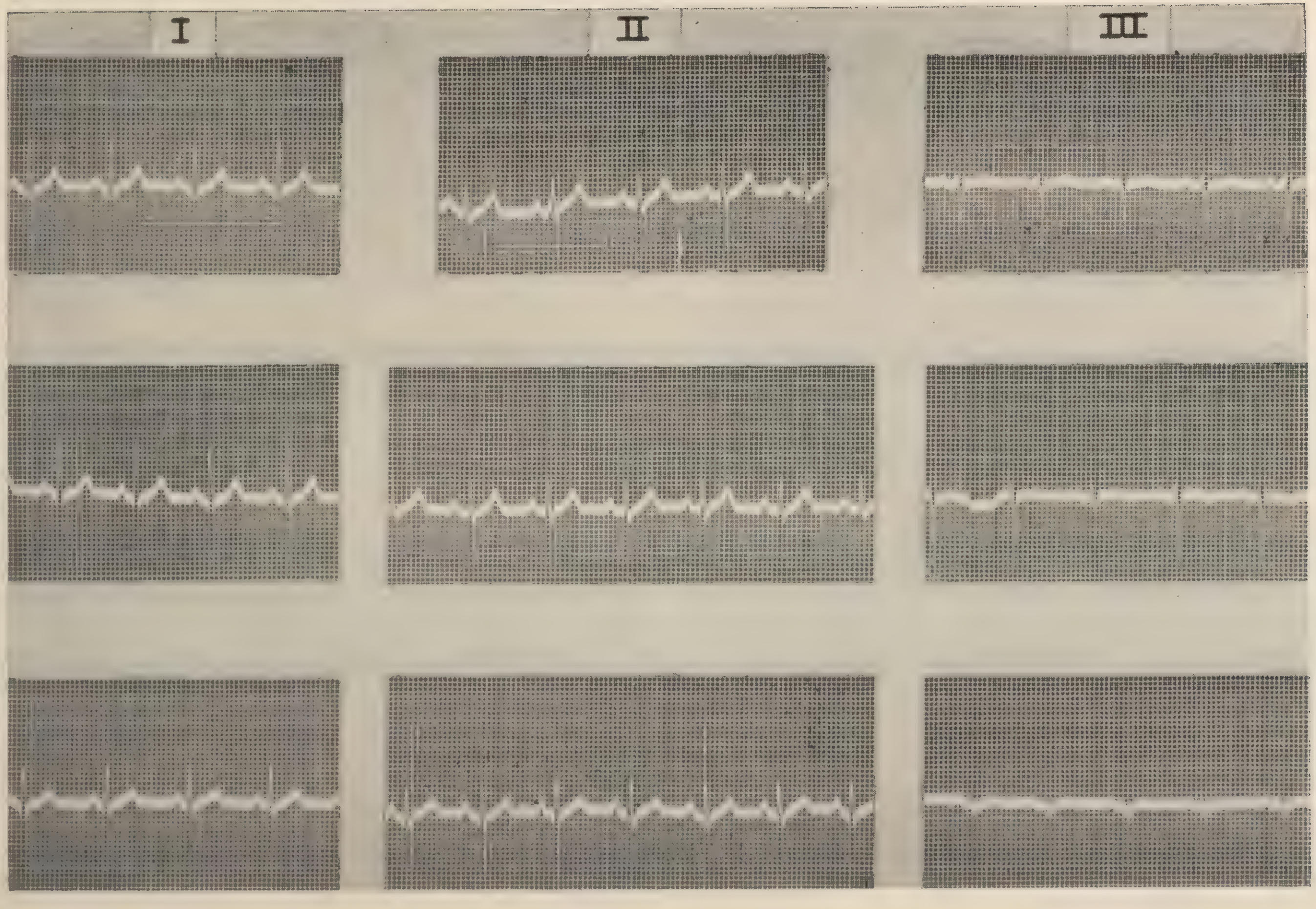

Fig. 3.—Control electrocardiograms before physical exertion. Upper tracings, subject supine; blood pressure, 122/74; heart rate, 87. Middle tracings, subject sitting; heart rate, 94. Lower tracings, subject erect; blood pressure, 118/88; heart rate, 100.

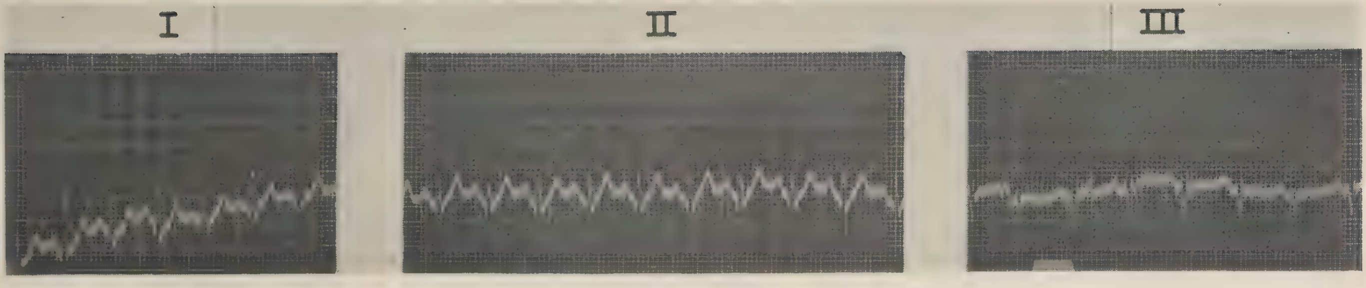

Fig. 4.—Electrocardiogram immediately after cessation of exercise. Subject seated; blood pressure, 182/88; heart rate, 150.

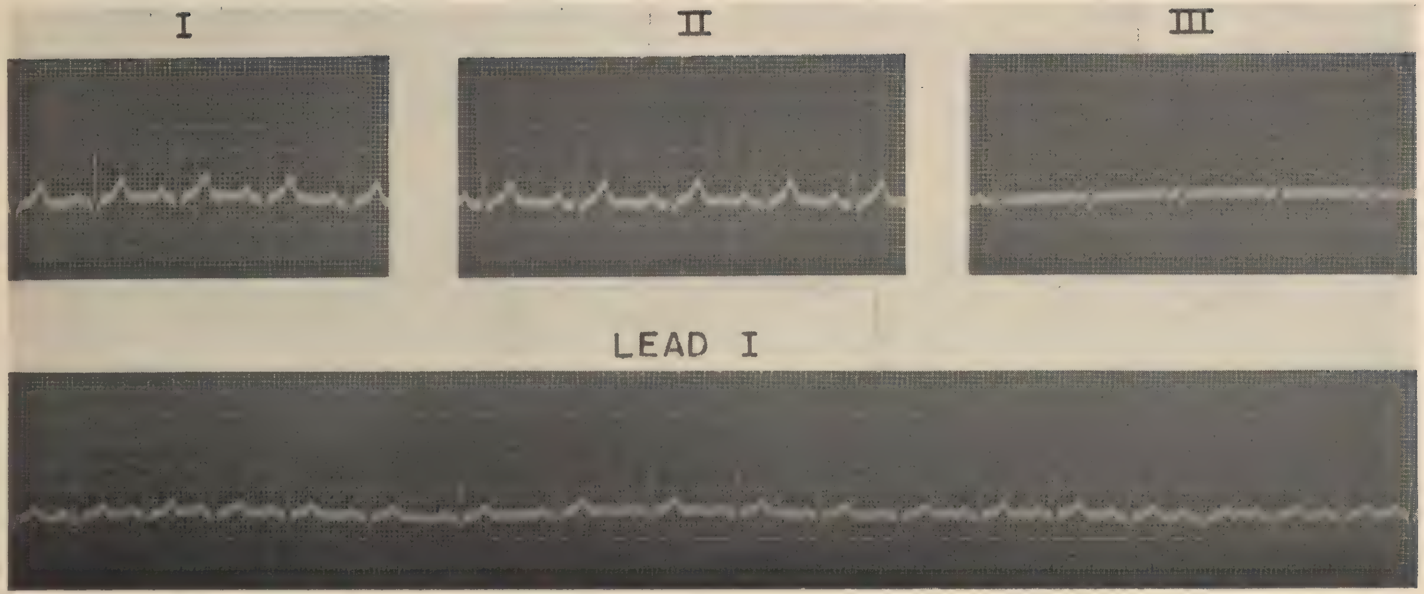

Fig. 5.—Upper tracing, electrocardiogram taken forty-five minutes after exertion. Subject supine, blood pressure, 108/76; heart rate, 90. Lower tracing, electrocardiogram (Lead I) taken in erect posture fifty-six minutes after exertion. Blood pressure, 100/92; heart rate, 105. Note transitory sinus slowing of cardiac rate in the middle of the tracing.

fell steadily, the diastolic blood pressure remained unchanged, and the pulse pressure narrowed markedly. The heart rate, instead of accelerating, slowed progressively. Signs of increasing discomfort and incipient syncope developed. After standing for two minutes and forty-five seconds of this period, the blood pressure was 100/90 and the heart rate, 99 per minute; the subject was in severe distress. Suddenly the heart rate slowed markedly and before the subject could be tilted flat, he lost consciousness, collapsed, and had a short clonic convulsion. After becoming supine, consciousness rapidly returned and, with it, apparently complete subjective recovery.

At the time of the collapse an electrocardiogram was being taken and is shown in Fig. 2. The two strips of this tracing are both Lead I and form a continuous record; the lower strip follows the upper one without a break in time. The tracing shows an increasing sinus bradycardia which leads to complete cardiac standstill. After 10.12 seconds of asystole (beginning of lower strip), the tracing is distorted by the muscular activity of the collapse and convulsion. A little over nineteen seconds (19.08) elapse between the onset of asystole and the first identifiable cardiac complex. This complex has a T wave of markedly increased amplitude which in subsequent complexes quickly reverts almost, but not quite, to the height of the pre-exercise control.

For comparison, pre-exercise control electrocardiograms in the supine, sitting, and 70 degree erect posture are shown (Fig. 3), as well as the tracing taken immediately (from thirty seconds to ninety seconds) after the cessation of work (Fig. 4).

Fig. 1 also shows that the postexertional orthostatic hypotension, syncope, and terminal bradycardia persisted for a considerable length of time. Syncope still occurred when the subject was upright, forty-three minutes (Period 8), fifty-one minutes (Period 10), and fifty-eight minutes (Period 12) after exertion. However, these periods showed a progressive improvement in the circulatory response to the erect posture. With each succeeding period the blood pressure was sustained for a progressively longer time before it suddenly fell and was accompanied by syncope and slowing of the heart rate. It was not until one hour and fifteen minutes after the cessation of exertion (Period 16) that the erect posture could be maintained for the required five minutes, and even then the circulatory response had not yet returned to normal. The widely fluctuating, often low, blood pressure and the markedly narrowed pulse pressure indicated a persisting circulatory instability.

Two electrocardiograms taken during this recovery period are shown in Fig. 5. The upper tracing, taken forty-five minutes after exertion and with the subject supine, is now similar to the pre-exercise control electrocardiogram. The lower tracing is Lead I taken fifty-six minutes after stopping work. The subject was erect; blood pressure, 100/92; pulse rate, 105 per minute. The transitory sinus slowing of the cardiac rate which appears in the middle of the tracing indicates that the conditions which produced the earlier asystole still persisted but to a very much milder degree.

DISCUSSION

The postexertional syncopal attack here described follows the pattern of vasovagal syncope described by Lewis.[17] The sudden cardiac slowing is generally attributed to vagal activity induced in turn by cerebral hypoxia. It has been demonstrated that marked vagal slowing of the heart occurs when the oxygen tension of the blood flowing to the brain is critically lowered[18,19] or when the volume of the blood flow to the brain is markedly reduced.[19,20] In the case here described the train of events is believed to have been as follows: hypotension produced deficient cerebral blood flow which resulted in cerebral hypoxia; the latter induced vagal stimulation of sufficient intensity to produce cardiac arrest.

The occurrence of asystole following physical exertion is reported largely because of its intrinsic interest. Here is a complete cardiac arrest induced by physiologic means. One speculates whether this episode may not have greater significance. Sudden death during or after exertion has been repeatedly encoun-

tered, even in apparently healthy young adults and athletes. Such deaths are usually attributed to a pathologic cardiac accident, generally coronary occlusion with myocardial infarction and terminal ventricular fibrillation. Where autopsy has been performed in such deaths, the overwhelming majority have revealed longstanding organic cardiac disease, often of a severe degree.[21-23] Occasionally no cardiac lesions are found. In both instances, *fresh* lesions capable of producing and explaining the immediate and sudden death are usually absent. This led Weiss[24] to call attention to the possibility that sudden death of this type might be the result not of an organic cardiac lesion but of purely circulatory changes, a "physiologic" death. He suggested a fatal vasovagal syncope. The present case demonstrates that cardiac arrest, presumably of vagal origin, can occur under certain circumstances following severe exertion and suggests that this phenomenon may persist for a considerable time after the cessation of effort. In a healthy youth, presumably with a good myocardium and coronary circulation, the heart and the subject recovered from the vagal arrest without apparent ill effect. Perhaps a heart involved by myocardial or coronary artery disease may not recover and death may ensue. Weiss has suggested that diseased hearts are more prone to reflex cardiac stimulation than normal hearts.

In the present case it is possible that the mild common cold may have played a significant role in the asystolic episode, for the circulation is known to be less stable during infections. Since fatality did not occur, this case cannot be regarded as indicating the mechanism of sudden death after exertion. For the same reason it cannot substantiate the hypothesis of fatal vasovagal syncope. It does, however, make this concept seem attractive.

SUMMARY

1. While standing erect following an episode of hard physical work, a normal young soldier suffered a syncopal attack during which a cardiac arrest for nineteen seconds occurred.

2. Such an asystole raises again the question whether sudden death during and after physical exertion may be the result of a fatal vasovagal syncope.

It is a pleasure to acknowledge the assistance of Major Edgar A. Blair, Infantry, Army of the United States, in this study, and the technical participation of Tec. 3 Howard Golden and Tec. 4 Wayland James.

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QUARTERLY PROGRESS REPORTS
1 January - 31 December 1947

AMRL

QUARTERLY PROGRESS REPORT

ON

RESEARCH AND DEVELOPMENT

PROJECTS

January 1947 to April 1947

PROJECT 54

Sub Project:- X-ray Stereopanoramograms. -- Mr. A. W. Carpenter, Chief Engineer.

The status of this sub project as set forth in the preceding quarterly report has not changed materially due to delay in delivery of special equipment, shortage of help and the press of higher priority work in the machine shop.

PROJECT 55

Sub Project:- Thermal Regulation During Fever. -- C. R. Park, Capt., MC and E. D. Palmes, 1st Lt., SnC.

This sub project as outlined in the preceding quarterly report is in the process of being edited in final report form.

PROJECT 57-2

Sub Project:- Efficiency of Signal Corps Operators in Extreme Cold. — Dr. E. A. Blair, Chief Physiologist and C. W. Gottschalk, 1st Lt., MC.

This sub project has appeared in final report form. (Report 57-2).

High Temperatures, Study of Physiological Effect of, AMRL 2-17. Approved in September 1942 in order to study the physiology of subjects in a hot environment.

Sub Project:- The Restoration of Thermal Balance During Acclimatization to Work in Desert Heat. — C. R. Park, Capt., MC and E. D. Palmes, 1st Lt., SnC.

This sub project appeared in final report form under the title, "Acclimatization to Work in the Heat; A study of the Physiology of Thermal Regulation in Man."

Survey of Foot Measurements and Proper Fit of Army Shoes, AMRL-53. Approved in September 1945 in order to study the fit of army shoes in relation to the general well being of the Army.

Sub Project:- Relation of Support in Arch of Shoes to Foot Physiology in Marching Troops. -- R. B. Magee, Capt., MC, G. C. Davis, Capt., MC and V. M. Milstead, Capt., MC. 0

No change from previous quarterly report except that analysis of the data has been completed and will soon appear in final report form.

Studies of Body Measurements as They Affect Physiological Efficiency, AMRL-54. Approved in May 1946 in order to study body measurements in relation to functional dynamics.

Sub Project:- Photoplanator. — Mr. A. W. Carpenter, Chief Engineer.

A laboratory model of the non-parallactic photoplanator, discussed in the preceding quarterly report, has been assembled using a high intensity source approximately .006 inches in diameter. The assembly shows something less than 2½ thousandths of an inch of parallactic deviation in dimensions up to 7 inches. (See accompanying illustration).

This apparatus has been used in connection with the Plastic Ear Mold sub project to make a comparative analysis of ear mold types and shapes.

A larger model is being constructed to provide an easy means of making accurate comparative measurements of soft tissues and easily deformable objects.

7-1

PHOTOPLANATOR
LABORATORY MODEL
A.M.R.L.
4/8/47
A.C.

<u>Cold, Study of the Physiological Effects of, AMRL 1-19</u>.
Approved in September 1942 in order to study the physiology of subjects in cold environments.

Sub Project:- Effects of Hypothermia on Vitamin A and Fat Metabolism in the Rat. -- Dr. K. P. McConnell, Biochemist and L. H. Tobin, 1st Lt., MC.

In the preceding quarterly report this sub project was entitled, "Effects of Subnormal Temperatures on Vitamin A Levels in Blood and Tissues of the Rat."

In the development of methods and techniques for the determination of Vitamin A in serum and various tissues unforseen difficulties were encountered. It has been found necessary to modify several steps in the standard method of Clausen and McCord in order to obtain the degree of accuracy required in these studies of the relationship of Vitamin A to fat metabolism at low temperatures.

A study was made of the effect of hypothermia on the moisture content of blood and tissues in order to establish any dilution factor that might be of significance in Vitamin A determinations. Adult rats were exposed to ambient temperatures around 0°F for periods of 2 to 9 hours. No significant changes in hemoconcentration or moisture content of the tissues were found except a slight increase in moisture content of the kidneys.

A series of experiments has revealed that there is a fairly consistent and "critical" point (about 87°F) in the rectal temperature curves of adult rats exposed to low ambient temperatures. At this point the animals begin a rapid decline to death. It has been shown by other investigators that the adrenals in hypothermia show an early depletion of lipoid substances, particularly cholesterol. The cholesterol content of the adrenals of rats at this "critical" temperature will be determined. Numerous studies on the so-called adaptation syndrome have focused much attention to the role of the adrenal cortex in conditions of stress such as cold, heat or shock.

Experiments done in collaboration with Dr. R. W. Clarke of this laboratory indicate that hypothermia produces a much more rapid depletion of liver glycogen in rats than a fast of the same duration at ordinary temperatures. It is planned to study the relationship of glycogen stores to the "critical" rectal temperature mentioned above.

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PROJECT 53

Sub Project:- Relation of Low-Heel Shoes to Foot Physiology in Marching Troops. -- H. E. Magee, Capt., MC, G. C. Davis, Capt., MC and V. M. Milstead, Capt., MC.

Forty-one (41) men participated under conditions essentially the same as those outlined for sub project "Relationship of Support in Arch of Shoes to Foot Physiology in Marching Troops". However, this group marched from 16 September 1946 to 29 November 1946, and thus the weather during the latter part of the experiment was considerably cooler. During the "conditioning" period the men wore their own "broken-in" footgear, but they wore combat boots instead of standard service shoes. This deviation from the standard practice was necessary because the men had not been issued type III service shoes during their basic training.

The low-heel shoes for this study were made by the Shelby Shoe Company of Salem, Mass. They had 1/2 inch spring rubber heels and were constructed using special lasts which provided the correct toe spring for the lower heel. Otherwise they were of the same construction as the standard service shoe.

After the completion of the 25-day "conditioning" period the subjects were fitted with new shoes. One half the men wore standard service shoes, and the other half wore the low-heel shoes for the 27-day experimental period. In all cases the men wore the same type shoes on both feet. Examinations were made twice daily by medical officers, and all findings were recorded for both periods.

The data obtained in this study are being organized and evaluated in preparation for the writing of the final report. The finished report with complete statements of findings will be submitted within a few weeks.

PROJECT 53

Sub Project:- Cinefluorographic Studies of the Shoe-Foot Relationship. — R. B. Magee, Capt., MC, G. C. Davis, Capt., MC and V. M. Milstead, Capt., MC.

Difficulties encountered in securing and installing the cinefluorographic equipment have prevented its being available for use at this time. Since it will not be available prior to the separation of the above investigators from the service, it is necessary for them to abandon the proposed study. It is hoped that the study will be included in future work at this laboratory. The equipment will be used to study the broader field of motion dynamics.

PROJECT 54

Sub Project:- Cineroentgenography. -- Mr. A. W. Carpenter, Chief Engineer.

Most of the parts of the necessary apparatus for this sub project (outlined in the preceding quarterly report) have been delivered and assembled. A power transformer to supply the project has been installed and considerable progress has been made in installing processing facilities to service the project. Actual construction of equipment is subject to higher priority work in the understaffed machine shop.

Studies of Body Reactions and Requirements under Varied Environmental and Climatic Conditions, AMRL-55. Approved in May 1946 in order to study physiological reactions as altered by varied conditions.

Sub Project:- Renal Circulation and Excretion in Man as Affected by Exercise. — Dr. R. W. Clarke, Physiologist, A. P. Crosley, Jr., 1st Lt., MC and P. J. Talso, 1st Lt., MC.

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Several experiments have been carried out on 5 human subjects. The subjects have been checked and standardized. The diuretic response to water ingestion was found to be fairly reproducible in each subject. Quantitative phenol red excretion studies have been made to be reasonably sure of no serious renal malfunction. The rates of chloride excretion and concentration were studied. Since the posterior pituitary may be involved in the renal changes being studied a few tests have been made to measure the effects of minute doses of pitressin on water and chloride excretion.

In a number of experiments, a period of marching on the treadmill has been included. The results were so variable that it will require the measurement of the various factors of renal function for their interpretation.

In preparation for clearance studies two different procedures were tested: 1) the single injection of para-aminohippurate as described by Alving, 2) the usual continuous infusion of mannitol and hippurate. The mannitol method of Smith, in our experience, was not sufficiently reliable so that of Corcoran has been tested and will be used in the future. The determination of the Tm of para-aminohippurate causes considerable distress to the subject so the method is being modified for future use. The recent report, by Barber and Clark, of the interference by para-aminohippurate in mannitol determinations by Smith's method has been quantitatively confirmed. This has furnished an additional reason for the adoption of the Corcoran method.

In view of the paper by Trueta on shunts in the renal circulation and their possible function during conditions of stress, it is planned to verify and extend the observations using animals. A cat was injected with radiopaque material and thick sections of the kidneys were X-rayed. The promising results on this one animal warrant a study to improve the technique for future work.

PROJECT 55

Sub Project:- The Aortic Factor in Hypertension. -- Dr. D. E. Gregg, Chief Research Physician, U. J. Collignon, Capt., MC and H. Schachner, 1st Lt., MC.

This sub project as outlined in the preceding quarterly report awaits special apparatus on order and suitable experimental animals. Animal quarters have just been completed and work will begin on this sub project as soon as the special apparatus is available.

Studies of Fatigue in Relation to Military Tasks, AMRL-56.

Approved in May 1946 in order to study the effects of stress and strain upon the body and the physiological factors that may be altered.

Sub Project:- A Critique of Physical Fitness Tests. — C. R. Park, Capt., MC, *et al*.

This sub project has been submitted in final report form. (Report 56-1).

PROJECT 55

Sub Project:- Development of a Polarographic Flow Meter. -- Dr. E. A. Blair, Chief Physiologist.

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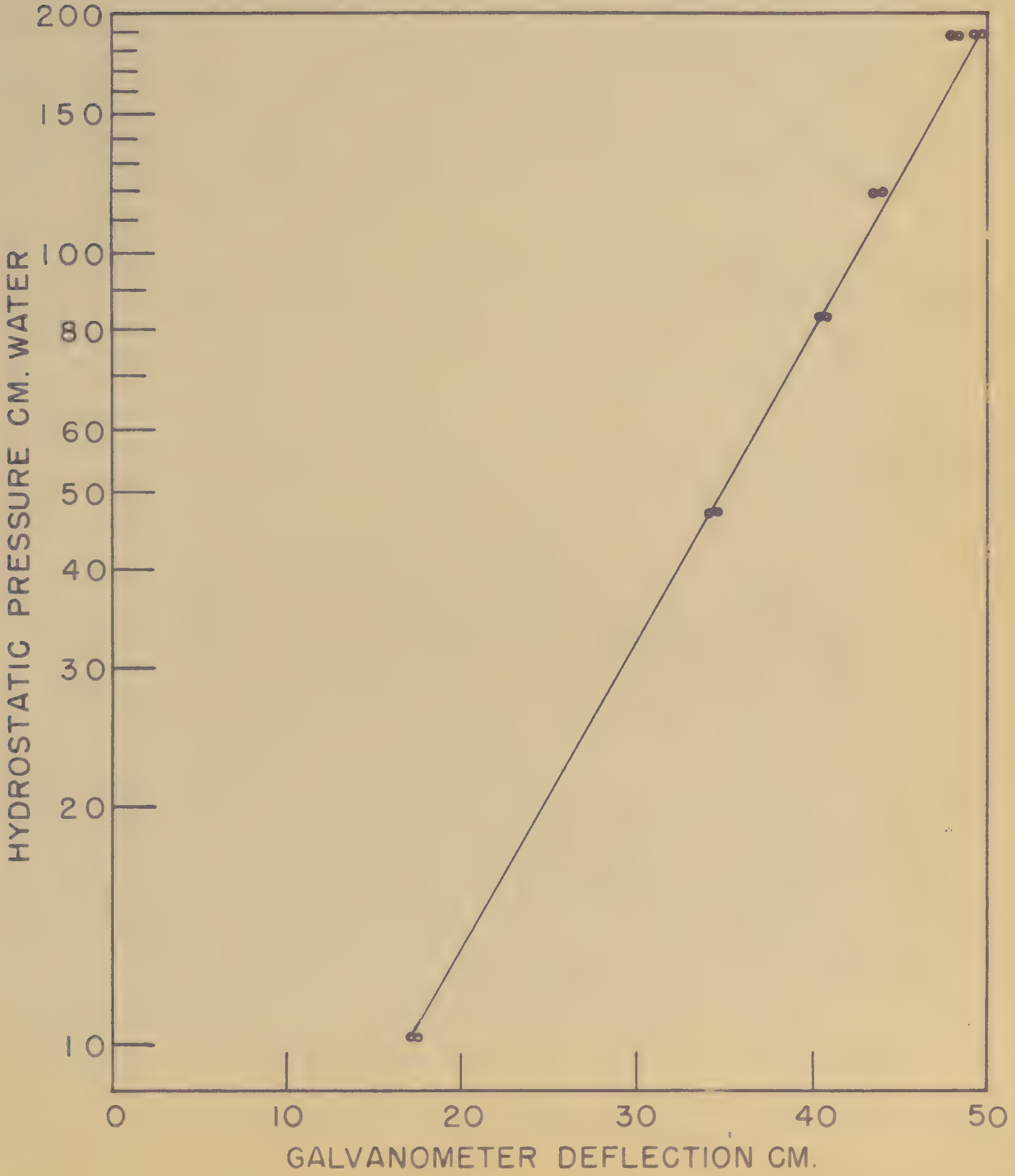
An experimental polarographic flow meter is under investigation, as a step in the development of a device for measuring the velocity of flow in blood vessels of men or unanesthetized animals. Stability has been increased by the use of a zinc-zinc sulfate half cell as the indifferent electrode, but there is still pronounced drift in the galvanometer reading when there is no fluid moving across the surface of the sensitive electrode.

When the velocity of a stream of 0.7% NaCl through a constant resistance and over the sensitive electrode is varied by changing the hydrostatic pressure, the galvanometer deflection resulting from short periods of flow appears to be proportional to the logarithm of the hydrostatic pressure (see Figure 1). For a given pressure, the separation between the two points in figure 1 indicates overshooting which occurs when the flow is started. The set of points in the upper right corner which are off the curve, are the first readings of the series; those, at the same pressure on the curve, are the last readings. The difference between these two sets of points is an expression of the change in the apparatus during the course of the determinations. Between each determination rebalancing to compensate for drift has been necessary. The investigation is now directed toward determining the cause of the slow drift in the apparatus.

FIGURE I

RELATION OF HYDROSTATIC PRESSURE CAUSING FLOW THROUGH POLAROGRAPHIC FLOWMETER TO GALVANOMETER DEFLECTION



PROJECT 55

Sub Project:- Relation of Dietary, Metabolic and Mechanical Factors to Atherosclerotic Lesions in the Rat. -- Dr. D. E. Gregg, Chief Research Physisian, U. J. Collignon, Capt., MC and H. Schachner, 1st Lt., MC.

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Progress to date on the sub project outlined in the preceding quarterly report is as follows: 1) apparatus for the determination of electrocardiograms, blood pressure and blood cholesterol have been constructed and the methods standardized; 2) control blood pressures have been established for all the rats, while control cholesterol values and electrocardiograms are available for some of the rats. One group has been started on a special diet containing cholesterol and thiouracil and another group has undergone an operation to induce hypertension.

PROJECT 55-1

Sub Project:- An Apparatus and Method for the Continuous Measurement of Evaporative Water Loss from Human Subjects. -- E. D. Palmes, 1st Lt., SnC.

This sub project has appeared in final report form. (Report 55-1). The material in it is to be used by Lt. Palmes as partial fulfillment for his doctorate. The material has also been submitted to the S.G.O. for publication approval.

PROJECT 55

Sub Project:- Observations on the Accuracy of the Electromagnetic Flow Meter. -- Dr. D. E. Gregg, Chief Research Physician, U. J. Collignon, Capt., MC and H. Schachner, 1st Lt., MC.

This sub project as outlined in the preceding quarterly report awaits requisite apparatus and machine shop work. Machine shop production has been severely curtailed due to shortage of help.

PROJECT 55-2

Sub Project:- Thermocouples for the Measurement of the Radiant Temperature of the Body. — E. S. Palmer, 1st Lt., SnC and C. B. Park, Capt., MC.

This sub project is appearing in final report form under the title, "Thermocouples for the Measurement of the Surface Temperatures of the Body". (Report 55-2).

PROJECT 55

Sub Project:- A Technique of Human Calorimetry. — E. D. Palmes, 1st Lt., SnC and C. R. Park, Capt., MC.

This sub-project as outlined in the preceding quarterly report is in the process of being edited in final report form.

PROJECT 55

Sub Project:- Analysis of Cortical Components Involved in Reflex Pupillary Dilitation to Clarify the Etiology of Anisocoria Resulting from Head Trauma. -- W. C. Wilson, 1st Lt., MC.

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Cortical and subcortical centers and fiber tracts producing pupillary dilitation have been demonstrated in cats by electrical stimulation. The structures involved are being located with a stereotaxic apparatus. Microscopis sections using the Weil technique will be used to identify the anatomy involved.

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The cerebral centers involved will be destroyed by electrocoagulation and the resulting retrograde degeneration will be traced by the Marchi method.

When the anatomical structures are clearly defined induced subdural hematomas with excitatory areas intact, and destroyed, will be used in animals to reproduce clinical signs.

Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks, AMRL-57. Approved in May 1946 in order to study the relationship of the soldier to his equipment, environment and task.

Sub Project:- Silica Content of Dust from Tank Ranges. — C. A. Kruse, 1st Lt., MC.

This sub project has been submitted in final report form. (Report 57-1).

PROJECT 57

Sub Project:- Plastic Ear Mold for Communications Equipment. -- J. H. St. John, 1st Lt., MC.

Plastic ear molds for the receivers of military communications equipment have been developed by the AGF Board No. 2 and have been referred to AMRL for an investigation of possible injuries from such molds under field conditions, and the possibility of producing a universal type ear mold.

The plastic ear molds have been made at this laboratory and approved by the personnel of the Medical Test Section of the AGF Board No. 2.

Shadow photographs of plastic ear molds have been made of twenty-five individuals in order to show the range of variations. Five representative molds are shown in Figure I. Figure II shows molds A, B, D and E with Mold C superimposed and acting as the reference mold. Trial insertion of different molds into one or more test subjects reveals that, while many ear molds may be forced into the ear, there is considerable distortion and consequent pressure both of the external ear and the external auditory meatus. Usually the foreign molds are either too loose or too tight for the ear and a good acoustic seal is not obtained. From early measurements and trial fittings of different ear molds, it seems highly improbable that a universal ear mold, even of graded sizes could be produced which would retain the features of comfort, adequate fitting, and a good acoustic seal.

The possibility of injuries to the ear while wearing the plastic ear mold from concussion of gun fire is now being investigated. Base line audiometric curves have been obtained on a group of test subjects and audiometric curves will be obtained in the field 15 minutes after firing and 24 hours later to determine whether the ear mold prevented injury or added to the temporary hearing loss due to concussion of gun fire.

Considerable difficulty has been experienced in obtaining suitable test subjects, an insulated ambulance and a power source for the audiometer in the field.

The possibility of injury to the ear from loud noises, such as may be encountered with the field radio is now under investigation on a group of men while operating tank radios in the moving vehicle. Preliminary audiometric curves have been obtained and will be compared with the recovery audiograms using both the plastic ear mold and the standard receiver headset.

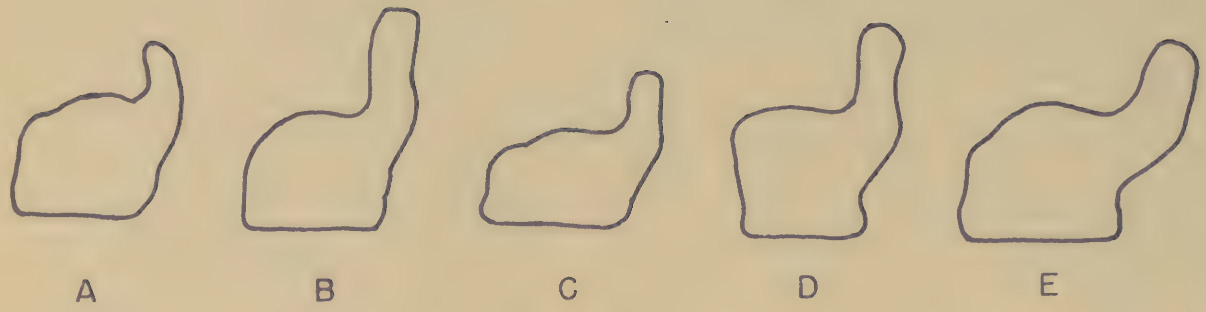

FIG. I

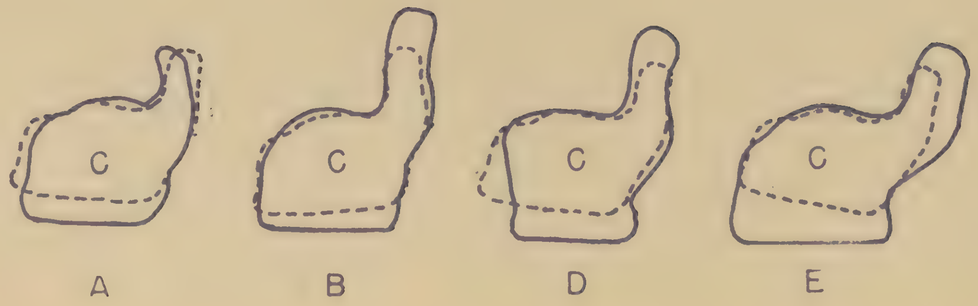

FIG. II

PROJECT 57

Sub Project:- Physical Fitness in Connection with OQMG Ration Test No. 4631.--
H. J. Spoor, 1st Lt., MC and G. C. Davis, Capt., MC.

The data from this sub project have been incorporated in the preliminary and final reports on Project No. 12 of the Medical Nutrition Laboratory, Chicago, Ill. Lt. Spoor went to Chicago to assist in the preparation of the final report.

PROJECT 57

Sub Project:- Application of Infra-Red Gas Analyser to the Study of Human Energy Metabolism. — H. J. Spoor, 1st Lt., MC and G. C. Davis, Capt., MC.

The preceding quarterly report abstracted pertinent data obtained from caloric expenditure studies of troops in mountain training during the test of operational rations at Camp Carson, Colorado, September 1946 (OQMG Ration Test No. 4631). These data demonstrated a practical field Ms. 9, technique for metabolic study which utilized the Leeds & Northrup Infra-Red Gas Analyzer sensitized to measure CO_2 selectively. Continuous graphic readings through use of an Esterline-Angus Recorder were obtained. Maneuverability, simulating portability, was obtained by use of the A-13 Oxygen Demand Mask on the subject to which was connected long air lines carried by cable and pulley rigging. The apparatus permitted continuous sampling of expired air over difficult mountain terrain.

Upon completion of the field studies it was reported that before the Infra-Red Gas Analyser could be recommended unreservedly for use in metabolic work, it would require subjection to rigorous laboratory standardization to ascertain particularly variations in receptive sensitivity of the instrument inherent to its construction. This study has been completed. Data have been obtained measuring specifically changes in response to various CO_2 concentrations with variation of flow rate, air circuit design, moisture contamination, temperature fluctuation and time. Metabolic studies on men under laboratory controlled conditions have been made. These studies include observations during rest, treadmill activity on the level and on grades at various speeds, and post-exercise recovery periods. The men chosen for subjects were of comparable age and stature to those studied during field trials.

All data directly related to adaptation of the Infra-Red Gas Analyser to estimation of CO_2 have been assembled. A complete report is being organized.

PROJECT 57

Sub Project:- Development of a Portable Apparatus for Study of Human Energy Metabolism. -- H. J. Spoor, 1st Lt., MC and P. J. Talso, 1st Lt., MC.

Nr.107

Field and laboratory adaptation of the Leeds & Northrup Selective Gas Analyzer to the estimation and continuous recording of respiratory CO_2 has indicated the advantages to be gained from completely portable apparatus for study of human energy metabolism. This equipment should measure continuously not only the CO_2 in expired air, but also respiratory volume and O_2 consumption.

Developments from the work on continuously recorded CO_2 have led to new techniques and the design of apparatus which record respiratory volume simultaneously with measured CO_2. These techniques can be adapted to a portable set-up. Electronic estimation of oxygen utilization is the next step to be accomplished. With this at hand, incorporation of recorders for CO_2 production, O_2 utilization and respiratory exchange into a single portable unit will be a matter of technical adaptation.

The ultimate aim of this sub project is to perfect an apparatus for the measurement of total energy exchange in man which will not only be sufficiently portable for use on difficult terrain but also adaptable to extremes of environmental conditions.

PROJECT 57

Sub Project:- Observations - Canadian Winter Operations. -- J. H. Blair, 1st Lt., MC and C. W. Gottschalk, 1st Lt., MC.

Two medical officers and two enlisted men have acted as observers for the Canadian Winter Operations at Fort Churchill, Manitoba, Canada. Data have been obtained on the following subjects and conclusions will be drawn after further analysis of the data.

1. Effect of stimulants, especially coffee, on steadiness: A abnormal amount of coffee is consumed by a high proportion of the personnel at Fort Churchill. The steadiness of coffee drinkers has been compared with non-drinkers by measuring the number of seconds, in a 30 second trial, that the subject allowed an electrode mounted on a pistol to come in contact with the rim of a hole target.

2. Effect of sweat depressants on moisture content of socks, the skin temperature and comfort in a cold environment: A sweat depressant powder has been developed and is under test to determine the effectiveness and value of such a powder in arctic operations.

3. The change in skin resistance resulting from the application of cold to a standard skin area: Tests are being made on subjects acclimatized to arctic environments for comparison with non-acclimatized or poorly acclimatized subjects to determine whether the test can be used as a measure of vascular response or as a method of preselection of personnel for duty in arctic environments.

4. The relation of personality, attitude and background to mental health in arctic environments: Personality and attitude tests prepared by Capt. Moody Bettis, MC., psychiatrist at the Rehabilitation Center, Fort Knox, Ky. have been carried out on 80 subjects and results will be analysed to determine the value of such tests in preselection of personnel for arctic duty.

5. In addition to the data mentioned above, information has been obtained on arctic conditions and problems of survival in extreme cold with a high wind chill factor, that will form a basis for laboratory cold room studies.

The Commanding Officer and the Research Director of AMRL visited Fort Churchill in order to observe and study the possibilities of establishing a permanent laboratory to study medical and physiological problems incident to arctic conditions. Plans are being developed in conjunction with the Canadian Research and Development group for the establishment of a permanent arctic medical research laboratory at Fort Churchill. Such a laboratory will have unusual opportunity to study the physiological factors involved in acclimatization.

PROJECT 57

Sub Project:- Observations - Frigid and Williwaw. -- Dr. G. W. Molnar, Physiologist, R. B. Magee, Capt., MC and E. L. Durrum, 1st Lt., MC.

Jn. 17,

An observation team from AMRL assigned to study medical aspects of cold weather operations arrived at Fairbanks, Alaska 14 November 1946, made observations at Point Barrow, Alaska 22 December 1946 to 8 January 1947 and at Adak 11 January to 30 January 1947. Additional observations were made at Fairbanks from 9 February to 4 March.

Data obtained during the various observations are now being compiled. These data include:

1. A comparison of the thermal responses of the Barrow Eskimo and white man to the Arctic winter. Both native Eskimo clothing and army issue arctic clothing were studied.

2. A study of thermal responses, heart rate and diuresis of troops confined to foxholes in a wet, windy, moderately cold environment for periods up to 18 hours.

3. A comparison of the diuretic effect of coffee and water on troops subjected to wet cold.

4. An analysis of the water requirements, urinary chlorides, caloric intake and weight changes during a 5-day field operation including marches and bivouacs in rugged terrain in a moderately wet windy environment.

5. A study of some blood constituents, heart rate, water balance, caloric intake and subjective sensations of 13 subjects during a 6-day field operation including bivouacs and daily marches on snowshoes at temperatures down to -32°C.

General information has been obtained on problems encountered by troops in cold weather operations which will be of value in formulating laboratory experiments.

A complete detailed report on the observations at Frigid and Williwaw will be submitted.

MDFRL

QUARTERLY PROGRESS REPORT

ON

RESEARCH AND DEVELOPMENT

PROJECTS

April 1947 to July 1947

Proj. 2,

This report indicates the progress made on the various projects during the past quarter. For full discussion of each project reference should be made to the preceding quarterly reports.

Two factors have contributed to delay in the progress of several projects.

1. Due to expansion it has become necessary to move the machine shop to another building. The delay and difficulty in obtaining building and construction materials, as well as sufficient labor, have retarded this move. This, along with a depleted shop staff, is reflected in the progress of the various projects requiring considerable shop work.

2. Enlisted men are used as laboratory technicians. These men must be trained in their particular duties. All the men who had been trained have been separated from the army this past quarter. Replacements with more than two or three months to serve have not been received as yet. Requests for enlisted men with more than a year to serve have been submitted.

PROJECT 54

Studies of Body Measurements as They Affect Physiological Efficiency. MDFRL-54. Approved in May 1946 in order to study body measurements in relation to functional dynamics.

Sub-Project:- Photoplanator
Sub-Project:- X-ray Stereopanoramograph.
Sub-Project:- Cineroentgenography -- Mr. A. W. Carpenter, Chief Engineer.

These projects, discussed in preceding quarterly reports, have been held up due to the interruption of machine shop operations incident to removal of the shop to new quarters and to the severe depletion of shop personnel as well as the higher priority placed upon shop work for other projects. It is anticipated that, with additional help in the new machine shop, work on these projects will proceed without further delay.

PROJECT 53

Survey of Foot Measurements and Proper Fit of Army Shoes. MDFRL-53. Approved in September 1945 in order to study the fit of army shoes in relation to the general well-being of the army.

Sub-Project:- Relation of Support in Arch of Shoes to Foot Physiology in Marching Troops.
Sub-Project:- Relation of Low-Heel Shoes to Foot Physiology in Marching Troops. -- R. B. Magee, Capt., MC, G. C. Davis, Capt., MC and V. M. Milstead, Capt., MC.

Since the experimental subjects and conditions for both these sub-projects were practically identical, the final reports are being combined into one report for distribution.

No further work is contemplated on Project 53.

PROJECT 2-17

High Temperatures, Study of Physiological Effects of, MDFRL 2-17. Approved in September 1942 in order to study the physiology of subjects in a hot environment.

Sub-Project:- Acclimatization to Heat; a Study of the Physiology of Thermal Regulation in Man. -- C. R. Park, Capt., MC and E. D. Palmes, 1st Lt., SnC.

This sub-project in final report form is being held in order that the final reports on other closely related sub-projects under Project 55 may be combined with it in a more comprehensive report. The joint report should be ready for distribution in the near future.

PROJECT 1-19

<u>Cold, Study of the Physiological Effects of, MDFRL 1-19</u>. Approved in September 1942 in order to study the physiology of subjects in cold environments.

Sub-Project:- Effects of Hypothermia on Vitamin A and Fat Metabolism in the Rat. -- Dr. Kenneth P. McConnell, Biochemist and L. H. Tobin, 1st Lt., MC.

The "critical" point in the cooling curve of rats (rectal temp. 87 ± 2°F) is that point at which the animals begin a rapid decline to death if cooling is continued. There appears to be a sex difference in the cooling curves. Planned studies on testicular function should give added information on this sex difference in relation to cold. Male and female animals having identical surface areas will be used.

The total adrenal cholesterol of chilled animals (at rectal temp. 87 ± 2°F) is reduced from 15 to 50%. Cholesterol - cholesterol ester determinations are being made. Tests will be made to determine if added cortical extracts will tend to prevent the fall in body temperature and/or aid recovery.

Experiments are being carried out to determine the relation of liver glycogen to Vitamin A levels. Studies to date show a more rapid depletion of liver glycogen on cooling than is obtained in fasting. Liver glycogen is completely depleted at or before the "critical" temperature (87 ± 2°F). Curves will be established for the correlation of glycogen depletion with blood glucose levels and rectal temperatures during cooling.

Histopathological studies of the adrenals of chilled animals and total base and mineral studies on blood, urine and tissues will be carried out.

PROJECT 55

Sub-Project:- A Method of Human Calorimetry.
Sub-Project:- Thermocouples for the Measurement of the Surface Temperature of the Body.
Sub-Project:- Thermal Regulation During Fever. -- C. R. Park, Capt., MC and E. D. Palmes, 1st Lt., SnC.

These three sub-projects have been completed. The final reports are being combined with the sub-project on "Acclimatization to Heat; A Study of the Physiology of Thermal Regulation in Man" and will be submitted as a comprehensive report.

PROJECT 55

Sub-Project:- Development of a Polarographic Flow Meter. -- Dr. E. A. Blair, Chief Physiologist.

M 22 An experimental flow meter has been shown to be amply sensitive for biological use, but stability is unsatisfactory. The slow, unpredictable change in the sensitive electrode precludes satisfactory calibration. Attempts to determine the cause of this change in sensitivity have been unsuccessful to date. The stability and sensitivity of the system using alternating currents will be investigated.

PROJECT 55

Studies of Body Reactions and Requirements under Varied Environmental and Climatic Conditions. MDFRL-55. Approved in May 1946 in order to study physiological reactions as altered by varied conditions.

Sub-Project:- Renal Circulation and Excretion as Affected by Exercise. -- Dr. R. W. Clarke, Physiologist, A. P. Crosley, Jr., 1st Lt., MC and P. J. Talso, 1st Lt., MC.

Renal clearance studies on dogs have been started. Dogs have been trained and will be used for the more critical phases of the study on the effects of exercise, cold, etc.

Studies have been carried out on the effects of local peripheral cold on kidney function in man. Glomerular filtration was measured by means of the mannitol clearance and renal blood flow by para-aminohippurate clearance.

The work on this project is being interrupted for the summer in order to permit these investigators to carry on field studies on water balance problems with Task Force Furnace.

PROJECT 55

Sub-Project:- The Aortic Factor in Hypertension.
Sub-Project:- Observations on the Accuracy of the Electromagnetic Flow Meter. --
Dr. D. E. Gregg, Chief Research Physician, U. J. Collignon, Capt., MC and
H. Schachner, 1st Lt., MC.

Additional work on these two sub-projects awaits the acquisition of appropriate apparatus and machine shop work.

PROJECT 55

Sub-Project:- Analysis of Cortical Components Involved in Reflex Pupillary Dilatation to Clarify the Etiology of Anisocoris Resulting from Head Trauma.— W. C. Wilson, 1st Lt., MC.

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The stereotaxic apparatus developed has proved very efficient in locating cortical and subcortical centers and fiber tracts which mediate reflex pupillary dilatation through the oculomotor nerve, ciliary ganglion and short ciliary nerves. The brains of the experimental cats are sectioned and stained by the Weil technique to permit identification of the anatomy involved.

PROJECT 55

Sub-Project:- Relation of Dietary, Metabolic and Mechanical Factors to Atherosclerotic Lesions in the Rat. -- Dr. D. E. Gregg, Chief Research Physician, U. J. Collignon, Capt., MC and H. Schachner, 1st Lt., MC.

Control blood pressures, blood cholesterols and electrocardiograms are now available for a considerable number of rats.

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Groups of rats are being continued on special diets containing cholesterol and thiouracil. Blood cholesterol levels are being maintained in these animals at two to three times the normal control values.

Hypertension has been induced by three procedures. Bilateral two-stage kidney operations either with partial occlusion of the renal arteries or with renal compression have been performed on approximately 100 rats. Following the first operation, most of these animals developed a transient hypertension but the time has been too short since the second operation for any conclusion regarding the creation of a permanent hyperpiesis. A third group of animals is being prepared in which the hypertension is induced by a one-stage operation with bilateral application of latex capsules to both kidneys.

PROJECT 56

Studies of Fatigue in Relation to Military Tasks. MDFRL-56. Approved in May 1946 in order to study the effects of stress and strain upon the body and the physiological factors that may be altered.

There were no sub-projects under Project 56 this quarter. The report on Physical Fitness Tests has been submitted.

PROJECT 57

Sub-Project:- Development of a Portable Apparatus for Study of Human Energy Metabolism. -- H. J. Spoor, 1st Lt., MC and P. J. Talso, 1st Lt., MC.

The preceding quarterly report cited new techniques and apparatus for recording respiratory volume. These findings are being applied to a portable respiratory assembly. Carbon dioxide measurement has been adapted. The measurement of oxygen utilization remains in the planning stage. Most of the necessary equipment for design of a portable apparatus has either been obtained or is on order.

PROJECT 57

Sub-Project:- Application of Infra-Red Gas Analyser to the Study of Human Energy Metabolism. -- H. J. Spoor, 1st Lt., MC and G. C. Davis, Capt., MC.

This sub-project has been completed and report will be submitted in the near future.

PROJECT 57

Sub-Project:- Observations--Frigid and Williwaw. -- Dr. G. W. Molnar, Physiologist, R. B. Magee, Capt., MC and E. L. Durrum, 1st Lt., MC.

The data obtained in Alaska on the variables outlined in the preceding quarterly report have been tabulated and analyzed. The first draft of the report is now being written.

PROJECT 57

Sub-Project:- Preliminary Observations on Physiological, Nutritional and Psychological Problems in the Arctic; Fort Churchill, Canada, Winter 1946-47. -- J. R. Blair, Capt., MC and C. W. Gottschalk, 1st Lt., MC.

This sub-project was briefly discussed in the preceding quarterly report under the title, "Observations - Canadian Winter Operations".

The final report which is a combination of a field trip report and scientific report with specific recommendations was submitted 1 July 1947.

PROJECT 57

<u>Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks. MDFRL-57</u>. Approved in May 1946 in order to study the relationship of the soldier to his equipment, environment and task.

✓ Sub-Project:-(Plastic Ear Mold for Communications Equipment.)--J. H. St. John, 1st Lt., MC.

Comparison of changes in audiometric curves when subjects are exposed to concussion from the firing of 90 mm. tank guns indicates that individual plastic ear molds afford some protection to the wearer.

Repeated otoscopic examinations have failed to show any damage to the ear either after long wearing (8 hours) or after removal and insertion of the molds every half hour for an eight hour period. No discomfort was noted by the test subjects who slept with the ear molds in place for eight hours.

The possibility of damage from loud noises incident to the operation of communication equipment in the field will be investigated at Task Force Furnace. Additional tests on the comfort of the ear molds under extreme heat (Task Force Furnace) will be compared with observers' reports on the comfort of the molds under extreme cold (Ft. Churchill, Canada).

MDFRL

QUARTERLY PROGRESS REPORT

ON

RESEARCH AND DEVELOPMENT

PROJECTS

July 1947 to October 1947

Proj. 37

AUTHORIZED PROJECTS

1. Cold, Study of the Physiological Effects of, M.D.F.R.L. 1-19. Approved 24 Sept. 1942.

2. High Temperatures, Study of Physiological Effects of, M.D.F.R.L. 2-17. Approved 24 Sept. 1942.

3. Survey of Foot Measurements and Proper Fit of Army Shoes, M.D.F.R.L. 53. Approved 11 Sept. 1945.

4. Study of Body Measurements as They Affect Physiological Efficiency, M.D.F.R.L. 54. Approved 31 May 1946.

5. Study of Body Reactions and Requirements under Varied Environmental and Climatic Conditions, M.D.F.R.L. 55. Approved 31 May 1946.

6. Studies of Fatigue in Relation to Military Tasks, M.D.F.R.L. 56. Approved 31 May 1946.

7. Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks, M.D.F.R.L. 57. Approved 31 May 1946.

PROJECT 1-19

Cold, Study of the Physiological Effects of, MDFRL 1-19. Approved September 1942 in order to study the physiology of subjects in cold environments.

Sub-Project:- Effects of Hypothermia on Vitamin A and Fat Metabolism in the Rat. — Dr. Kenneth P. McConnell, Biochemist and L. H. Tobin, Capt., M.C.

Jn-17

A series of experiments on 20 rats has been carried out in the study of the effects of hypothermia on Vitamin A metabolism. Analysis of results indicates that some mobilization of Vitamin A in the liver was caused by hypothermia. In view of these findings a similar experiment using a larger number of animals is now in progress to substantiate these findings.

Adrenal and serum cholesterol determinations have been completed on a series of 31 animals of which approximately two thirds represented chilled rats and one third normal controls. Although the results have been subjected to partial statistical analysis further analysis awaits the completion of work now in progress. The procedure for the fractionation of cholesterol and cholesterol ester described in the last quarterly report has been worked out and is now in operation. The chromatographic method of cholesterol determination has not gone beyond the planning stage due to difficulty in obtaining key chemicals.

PROJECT 1-19

Sub-Project:- Study of the Effects of Sub-normal Temperatures on the Metabolism of Various Phosphorous Compounds in Rats. -- Dr. H. F. Jensen, Chief Biochemist, E. L. Durrum, Capt., M.C. and R. N. Cagan, 1st Lt., M.C.

Data on the changes in the content of liver glycogen and of blood glucose due to cold have been obtained in this laboratory (See Sub-projects under 1-19) and by other investigators.

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Phosphorylation plays an important role in the mechanisms of storage and mobilization of energy for maintenance of normal metabolism. The formation of ester phosphate linkages are of vital importance in the regulation of catabolism of carbohydrate. It is proposed to study:

1. The content of glucose-6-phosphate in various tissues. The first step in the utilization of glucose by animal tissue, a step common to its transformation to glycogen or its oxidation, is the formation of glucose-6-phosphate.

2. The content of adenosine triphosphate in various tissues. Adenosine triphosphate (ATP) is the bearer of the chemical energy generated in the course of metabolic processes.

Determinations of these tissue constituents are to be done by colorimetric methods; enzymic and manometric techniques; and the employment of radioactive isotopes as tracers. It is contemplated to work out a set of analytical procedures for the determination of glucose-6-phosphate and ATP which can also be employed in a similar study of the effect of other environmental influences such as heat and radiation.

A study of the effect of administration of hormones, vitamins and various chemical substances (glucose, phosphate, Mg^{XX}, K^{X}, etc.) on the possible changes in the content of glucose-6-phosphate and ATP of various tissues, observed on exposure of animals to low temperatures, is planned.

PROJECT 2-17

High Temperatures, Study of Physiological Effects of, MDFRL 2-17. Approved September 1942 in order to study the physiology of subjects in a hot environment.

Sub-Project:- Thermal Regulation During Early Acclimatization to Work in a Hot Dry Environment. — C. R. Park, Capt., M.C. and E. D. Palmes, Capt., Sn.C.

Published as M.D.F.R.L. Report 2-17-1, 30 June 1947.

PROJECT 53

Survey of Foot Measurements and Proper Fit of Army Shoes. MDFRL-53. Approved September 1945 in order to study the fit of army shoes in relation to the general well-being of the army.

Sub-Project:- Observations on the Relation of Height of Heel and Support in Arch of Shoes to Foot Physiology in Marching Troops. — R. B. Magee, Capt., M.C., G. C. Davis, Capt., M.C. and V. M. Milstead, Capt., M.C.

Published as M.D.F.R.L. Report 53-1, 16 September, 1947.

PROJECT 54

Studies of Body Measurements as They Affect Physiological Efficiency. MDFRL-54. Approved May 1946 in order to study body measurements in relation to functional dynamics.

Sub-Project:- Photoplanator. -- A. W. Carpenter, Chief Engineer.

The final report is now in press.

PROJECT 54

Sub-Project:- X-ray Stereopanoramograph.
Sub-Project:- Cineroentgenography. — A. W. Carpenter, Chief Engineer.

Progress on these sub-projects has been further delayed due to inability to secure necessary materials and special equipment.

PROJECT 55

Studies of Body Reactions and Requirements under Varied Environmental and Climatic Conditions. MDFRL-55. Approved May 1946 in order to study physiological reactions as altered by varied conditions.

Sub-Project:- Renal Circulation and Excretion as Affected by Exercise. — Dr. R. W. Clarke, Physiologist, A. P. Crosley, Jr., Capt., M.C. and P. J. Talso, Capt., M.C.

Due to participation by Dr. Clarke and Capt. Talso in the activities of Task Force Furnace, as well as the fact that a new sectional laboratory was under construction, work discussed in the last quarterly report was temporarily curtailed.

Despite these delays experiments have been carried out testing the validity of the use of mannitol as a measure of glomerular filtration rate. This was accomplished in dogs by comparing simultaneous exogenous creatinine and mannitol clearances. In dogs creatinine is excreted exclusively by glomerular filtration. Comparison of the clearance values of these two substances indicates that mannitol is a satisfactory substance for measuring glomerular filtration rate in the dog.

The applicability of semi-micro techniques to the analysis of mannitol and sodium para-amino hippurate has been accomplished wherein only 0.5 ml. of plasma is required. These procedures will obviate the necessity of drawing large samples of blood during clearance experiments and make the use of small laboratory animals more practical.

All procedures necessary to carry out experiments on the effect of local peripheral cold on renal function have been worked out and as soon as suitable human subjects are available investigations will proceed.

PROJECT 55

Sub-Project:- Development of a Polarographic Flow Meter. — Dr. E. A. Blair, Chief Physiologist.

An experimental flow meter has been shown to be amply sensitive for biological use, but stability is unsatisfactory. The slow, unpredictable change in the sensitive electrode precludes satisfactory calibration. Attempts to determine the cause of this change in sensitivity have been unsuccessful to date. The stability and sensitivity of the system using alternating currents is being investigated.

PROJECT 55

Sub-Project:- Relation of Dietary, Metabolic and Mechanical Factors to Atherosclerotic Lesions in the Rat. — Dr. D. E. Gregg, Chief Research Physician, U. J. Collignon, Capt., M.C., H. Schachner, 1st Lt., M.C., and W. E. Nerlich, 1st Lt., M.C.

No. 57

Control electrocardiograms have been completed on all rats and their blood pressures are being taken at bi-weekly intervals.

No persistent hypertension satisfactory for the purpose of this experiment has been obtained so far by any of the three methods tried. While the rats with partial occlusion of the renal arteries and with the bilateral renal compression operation still exhibit normal blood pressure, the one-stage operation with bilateral application of latex capsules to the kidneys has resulted in a significant elevation of blood pressure. However, the survival time in the latter has been too short to permit the studies desired. The above procedures for inducing hyperpiesis are being reinvestigated.

The special diets are being continued and serum cholesterols are taken periodically.

PROJECT 55

Sub-Project:- The Aortic Factor in Hypertension.
Sub-Project:- Observations on the Accuracy of the Electromagnetic Flow Meter. --
Dr. D. E. Gregg, Chief Research Physician, U. J. Collignon, Capt., M.C. and
H. Schachner, 1st Lt., M.C.

Work on these two sub-projects still awaits the acquisition of appropriate apparatus and machine shop work.

PROJECT 55

Sub-Project:- A Method of Human Calorimetry. -- E. D. Palmes. 1st Lt., Sn.C. and C. R. Park, Capt., M.C.

Published as M.D.F.R.L. Report 55-3, 1 April 1947.

PROJECT 55

Sub-Project:- An Improved Mounting for Thermocouples for the Measurement of the Surface Temperature of the Body. -- E. D. Palmes, 1st Lt., Sn.C. and C. R. Park, Capt., M.C.

Published as M.D.F.R.L. Report 55-2, 18 March 1947.

PROJECT 55

Sub-Project:- Thermal Regulation During Fever. — C. R. Park, Capt., M.C. and E. D. Palmes, Capt., Sn.C.

This sub-project is now in the process of publication.

PROJECT 55

Sub-Project:- A Possible Humoral Factor in Human Thermal Regulation. -- Dr. E. D. Palmes, Physiologist, H. Schachner, 1st Lt., M.C., R. E. Albert, 1st Lt., M.C. and J. J. Hart, Cpl.

M.6)

A working man consistently exhibits a higher rectal temperature than the same man under basal conditions. This elevation is dependent upon the work rate within broad limits of environmental conditions. The present study is an attempt to demonstrate a humoral factor as the basic agent responsible for this elevation in temperature. The experimental procedure for the demonstration of such an agent will consist of the transfer of blood from the working to the resting subject. The presence of the humoral agent could then be detected by changes in thermoregulation tending to produce an elevation of temperature in the resting subject. Since only a small fraction of the body blood can be transferred it would be expected that only small and/or transient effects will occur. The demonstration will depend on the rapidity with which thermoregulatory changes can be measured. Apparatus previously developed at this laboratory is capable of measuring changes of the type expected.

[1]

PROJECT 55

Sub-Project:- Analysis of Cortical Components Involved in Reflex Pupillary Dilatation to Clarify the Etiology of Anisocoria Resulting from Head Trauma. -- W. C. Wilson, Capt., M.C.

M.7)

The stereotaxic apparatus developed has proved very efficient in locating cortical and subcortical centers and fiber tracts which mediate reflex pupillary dilatation through the oculomotor nerve, ciliary ganglion and short ciliary nerves of cats.

Weil stained sections of the brains have revealed the excitable centers to be in the frontal lobe gyrii, proeus and genualis and the caudate nucleus.

Prefrontal lobotomies involving the afore-mentioned gyri are being performed. Their subcortical connections are being traced by the retrograde degeneration technique of Marchi.

PROJECT 55

Sub-Project:- Development of a Photoelectric Polarimeter with Variable Electric Field. — E. L. Durrum, Capt., M.C.

A study of the degree of rotation, which a protein solution will impart to a beam of polarized light when the protein solution is subjected to an intense electrostatic field, is contemplated. It is hoped that the information so obtained will be useful for purposes of classification and identification of proteins in complex solutions such as blood serum or other body fluids.

An apparatus is being developed to make these measurements. In its present form, the apparatus comprises a light source with a filtered beam to give a monochromatic source. This beam is then passed through a polaroid disc, thence through a square cross-sectional couvette, containing the solution to be investigated and on through a second polaroid disc analyzer whose rotation with respect to the polarizer may be measured. The beam passes on to a photoelectric cell, which is in turn coupled to an electronic amplifyer and bridge circuit which is connected to a delicate micro-ammeter as an indicator.

The couvette holder is provided with two parallel brass electrodes across which a high voltage (5000 V) source is connected. Upon applying this potential across the electrodes, the plane of the beam of polarized light is rotated during passage through the protein solution thereby causing a change in the amount of light reaching the photoelectric cell. By adjusting the meter to zero reading, it is possible to measure the degree of rotation for a given field strength.

In its present form, the apparatus is not of sufficient sensitivity for practical measurements. Several changes are being made which it is hoped will increase the sensitivity of the apparatus. These changes include replacement of polaroid discs with Nicol's prisms, increasing the field strength by utilizing specially designed "thinner couvettes" and increasing the applied potential across the solution.

PROJECT 56

Studies of Fatigue in Relation to Military Tasks. MDFRL-56. Approved May 1946 in order to study the effects of stress and strain upon the body and the physiological factors that may be altered.

There were no sub-projects under Project 56 this quarter.

PROJECT 57

<u>Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks. MDFRL-57</u>. Approved May 1946 in order to study the relationship of the soldier to his equipment, environment and task.

Sub-Project:- Plastic Ear Mold for Communications Equipment. — J. H. St. John, Capt., M.C.

Published as M.D.F.R.L. Report 57-5, 30 September 1947.

PROJECT 57

Sub-Project:- Application of the Infra-Red Gas Analyzer to the Study of Human Energy Metabolism. — H. J. Spoor, Capt., M.C. and G. C. Davis, Capt., M.C.

Published as M.D.F.R.L. Report 57-4, 21 August 1947.

PROJECT 57

Sub-Project:- Development of a Portable Apparatus for Study of Human Energy Metabolism. -- H. J. Spoor, Capt., M.C. and P. J. Talso, Capt., M.C.

(N. 9)

Carbon dioxide measurement utilizing the infra-red gas analyzer has been thoroughly studied. Previous quarterly reports cited new techniques and apparatus design for recording respiratory volume. The above knowledge has been applied to "breadboard" construction of a portable respiratory apparatus. The apparatus has been designed only for carbon dioxide and volume analysis, but is capable of including the proposed oxygen analysis units upon their development. It consists of (1) the mask assembly, A-13 oxygen demand, with modifications for temperature change adaptation; (2) a pack board containing the analyzing units of the infra-red selective gas analyzer (i.e. light source, analysis cell and thermopile assembly for CO analysis) and an orifice flow, activated differential pressure volume gauge with microtorque potentiometer for instantaneous volume analysis; (3) 350 feet of intertank communication cable (CD 13) connecting the pack board assembly to recording instruments; and (4) appropriate continuous recording instruments plus adequate power source and impulse amplification circuits.

Preliminary volume standardization has been completed. Sensitivity adjustment of the instrument to known carbon dioxide is in process. Selected volunteers will be subjected to comparative respiration studies under extremes of temperature and varying degrees of exertion. Completion of this series satisfactorily will justify presentation of detailed blueprints of the apparatus for precision manufacture.

[1

PROJECT 57

Sub-Project:- Development of Electronic Oxygen Analyzer for Adaptation to Portable Metabolic Apparatus. — H. J. Spoor, Capt., M.C. and J. H. St. John, Capt., M.C.

ws-10

Electronic estimation of oxygen utilization for use in conjunction with carbon dioxide and respiratory volume recording constitutes the final step in development of a complete portable metabolic apparatus. Literature survey has led to the conclusion that the requisite equipment must be both developed and adapted. Upon satisfactory development it will be adapted to the existing "breadboard" model of a portable apparatus for study of human energy metabolism.

PROJECT 57

Sub-Project:- Observations--Frigid and Williwaw. -- Dr. G. W. Molnar, Physiologist, R. B. Magee, Capt., M.C. and E. L. Durrum, Capt., M.C.

The final report of these observations is now in press.

PROJECT 57

Sub-Project:- Preliminary Observations on Physiological, Nutritional and Psychological Problems in Extreme Cold; Fort Churchill, Canada, Winter 1946-47. — J. R. Blair, Capt., M.C., F. W. Urbush, Tech. Sgt., and I. T. Reed, Tech. 4.

Published as M.D.F.R.L. Report 57-3, Restricted, 3 July 1947.

PROJECT 57

Sub-Project:- Studies of Physiological Problems under Field Conditions in Extreme Cold; Fort Churchill, Manitoba, Canada, Winter 1947-48. — Dr. G. W. Molnar, Physiologist, J. R. Blair, Capt., M.C., C. W. Gottschalk, Capt., M.C., C. A. Johnson, 1st Lt., M.C., L. E. Osgood, 1st Lt., M.C., and W. J. Zimmerman, 1st Lt., M.C.

During the winter of 1947-48 a series of field experiments under arctic winter weater conditions will be carried out at Fort Churchill, Manitoba, Canada. Preliminary studies and basal determinations on eight test subjects are being made in bivouac on the Fort Knox Reservation and in the Cold Room of the Medical Department Field Research Laboratory. Upon completion of these observations the eight test subjects and five research personnel will go to Fort Churchill, where the same experiments will be repeated under severe arctic winter weather conditions. This program will include the following studies:

1. Cooling rate and tolerance times of resting men protected by army evacuation equipment in arctic winter weather. After lying on the ground for a known period of time, a man will be put through the necessary performance for emergency aid and evacuation. By following skin and rectal temperatures thermoelectrically the cooling rate of the simulated casualties will be observed. Subjective symptoms in relation to comfort and cold exposure will be recorded. Various types of evacuation equipment will be compared, and the time for procedures and difficulties involved will be carefully noted. The effects of the weather on the medical men will also be observed.

2. Effectiveness of sweat control by means of anhidrotic foot powders. Studies begun last winter at Fort Churchill will be continued to determine the maximum anhidrosis which can be obtained with these agents and the effect of activity and environmental temperature on the degree of anhidrosis. The value of anhidrotic effects obtained will be determined by comparing, in the same subject, the skin temperatures and comfort of treated and untreated feet. The anhidrotic effect, after treatment has been discontinued, will be followed at indicated intervals until the character of the curve of residual effect is apparent. Both the feet and the footwear of test subjects will be examined frequently for any deleterious effects produced by the anhidrotic agents employed.

3. The state of water balance of troops during arctic winter field operations. Water intake and urinary output will be followed in eight test subjects. Following the period of preconditioning to marching with packs, subjects will go into bivouac for two weeks on the Fort Knox Reservation. All measurements will be performed in the same manner at Fort Knox as contemplated for Churchill. Upon their return to the barracks, special tests will be run to ascertain the reactions of the men to heat and cold. About the 1st of January the men will proceed to Churchill. In February they will go into bivouac for two weeks, and repeat the routine carried through in the Fort Knox study. They will leave Fort Churchill about 15th April, and their reactions to heat and cold will again be tested at Fort Knox during May.

To be able to interpret the water-turnover data, and to be able to assess the influence of possible dehydration, the following additional measurements will be performed: body temperature, basal metabolism, caloric intake, pulse rates, blood and urinary constituents, and psychological reactions.

4. The physiology of rewarming following exposure to cold. After exposure to cold under known conditions, men will be exposed to diverse external sources of heat. At Fort Knox, they will be exposed in the cold room and rewarmed in the laboratory. At Churchill they will be exposed to the outdoors, and rewarmed in the sunshine and by open fires. Body temperatures, pulse rates, and subjective reactions will be measured. This project will be integrated with the water balance study.

PROJECT 57

Sub-Project:- Physiological Observations, Task Force Furnace. — Dr. R. W. Clarke, Physiologist and P. J. Talso, Capt., M.C.

Data in the form of chemical analyses of urine samples collected during hydration experiments in the desert are now being tabulated and the final report is in progress.

MDFRL

QUARTERLY PROGRESS REPORT

ON

RESEARCH AND DEVELOPMENT

PROJECTS

October 1947 to January 1948

Proj. 4,

AUTHORIZED PROJECTS

P-6-64-12-02	Cold, Study of the Physiological Effects of. Approved 24 Sept. 1942.
P-6-64-12-03	High Temperatures, Study of Physiological Effects of. Approved 24 Sept. 1942.
P-6-64-12-05	Study of Body Measurements as They Affect Physiological Efficiency. Approved 31 May 1946.
P-6-64-12-06	Study of Body Reactions and Requirements under Varied Environmental and Climatic Conditions. Approved 31 May 1946.
P-6-64-12-07	Studies of Fatigue in Relation to Military Tasks. Approved 31 May 1946.
P-6-64-12-08	Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks. Approved 31 May 1946.

PROJECT E-6-64-12-02

Cold, Study of Physiological Effects of. Approved 24 Sept. 1942 in order to study the physiology of subjects in cold environments.

Sub-Project M.D.F.R.L. 02-1: Studies of Physiological Problems under Field Conditions in Extreme Cold - Dr. G. W. Molnar, Physiologist, J. H. Blair, Capt. MC, C. W. Gottschalk, Capt., MC, L. W. Osgood, 1st Lt., MC, W. J. Zimmerman, 1st Lt., MC and H. E. Layton, 1st Lt. MC.

During the winter of 1947-48 a series of field experiments under arctic weather conditions will be carried out at Ft. Churchill, Manitoba, Canada. Preliminary studies and basal determinations on eight test subjects were made on the Ft. Knox Reservation and in the cold room of the laboratory. Upon completion of these observations the subjects and five research personnel went to Ft. Churchill (1 Jan.) where the same experiments will be repeated under severe arctic winter conditions.

In addition to valuable basic data and experience gained during the preliminary studies it was learned that excretions of creatinine varied ten to twenty-five per cent from day to day thus precluding use as an index of the completeness of daily urinary collections. The preliminary test also indicated the need for supplementing the C-2 ration to insure against weight loss.

If the experimental program for Churchill can be executed as designed, a moderate dehydration in some of the men can be anticipated during the second week in bivouac. In order to assess the physiological effects of this dehydration other stresses, including exercise, cold weather and insufficient sleep, will be placed under control and measured.

The program at Churchill will include the following studies:

1. Cooling rate and tolerance times of resting men protected in army evacuation equipment in arctic winter weather. After lying on the ground for a known period of time, a man will be put through the necessary performance for emergency aid and evacuation. By following skin and rectal temperatures thermoelectrically the cooling rate of the simulated casualties will be observed. Subjective symptoms in relation to comfort and cold exposure will be recorded. Various types of evacuation equipment will be compared, and the time for procedures and the difficulties involved will be carefully noted. The effects of the weather on the medical men will also be observed.

2. Effectiveness of sweat control by means of anhidrotic foot powders. Studies begun last winter at Ft. Churchill will be continued to determine the maximum anhidrosis which can be obtained with these agents and the effect of activity and environmental temperature on the degree of anhidrosis. The value of anhidrotic effects obtained will be determined by comparing, in the same subject, the skin temperatures and comfort of treated and un-

treated feet. The anhidrotic effect, after treatment has been discontinued, will be followed at indicated intervals until the character of the curve of residual effect is apparent. Both the feet and the footwear of test subjects will be examined frequently for any deleterious effects produced by the anhidrotic agents employed.

3. The state of water balance of troops during arctic winter field operations. Water intake and urinary output will be followed in eight test subjects. All measurements will be performed in the same manner at Churchill as were done at Knox during the preliminary studies. The subjects will leave Ft. Churchill about 1 April, and their reactions to heat and cold will again be tested at Ft. Knox during May.

To be able to interpret the water-turnover data, and to be able to assess the influence of possible dehydration, the following additional measurements will be performed: body temperature, basal metabolism, caloric intake, pulse rates and blood and urinary constituents.

4. The physiology of rewarming following exposure to cold. At Churchill the subjects will be exposed to the outdoors, and rewarmed in the sunshine and by open fires. Body temperatures, pulse rates, and subjective reactions will be measured. This project will be integrated with the water balance study.

PROJECT B-6-64-12-02

Sub-Project M.D.F.R.L. 02-3: Observations--Frigid and Williwaw - Dr. G. W. Molnar, Physiologist, A. D. Magoe, Capt., MC and E. L. Durrum, Capt., MC.

The final report is now in press.

One phase of these observations was presented as a paper, entitled "Factors Influencing Endurance in Wet, Cold Environment", at the Symposium on Military Physiology held at the Army Medical Center, 4-6 Dec. 1947.

PROJECT [illegible]-6-64-12-02

Sub-Project M.D.F.R.L. 02-3: Effects of Hypothermia on Vitamin A and Fat Metabolism in the Rat - Dr. Kenneth P. McConnell, Biochemist and L. H. Tobin, Capt., MC.

765.21

Two series of experiments have been carried out investigating the effects of hypothermia on the vitamin A stores in livers of white rats. Male and female rats were exposed to ambient temperatures of 0 ± 3°F. All the animals were chilled to a body temperature of 70°F. Another series of animals was exposed to ambient temperatures of 24 ± 2°F. The terminal rectal temperatures of these animals in most cases did not reach 70°F. In both series it required a longer time for male animals to reach the terminal rectal temperature. The reduced ambient temperatures caused a definite change in liver vitamin A. The normal vitamin A liver level in female rats was markedly higher than that for males. Despite the use of a standard diet there was a fairly wide variation in the vitamin A content of the normal liver. In order to stabilize liver vitamin A values the diet was supplemented with known amounts of vitamin A.

Attention has been called to the vitamin A content of the adrenals and its possible function in adrenal activity under a specific stress (in this case hypothermia). Other constituents of the adrenal such as vitamin C and cholesterol show marked changes with certain types of stress. It appears that the drop in adrenal cholesterol due to hypothermia is dependent not so much on the intensity of the stress applied as it is on the duration of time over which the stress is applied. It was noted that there are definite and statistically significant changes in all the cholesterol fractions of both sera and adrenals of animals subjected to long exposures.

A series of experiments involving the use of various hormones has been formulated on the basis of results obtained in this laboratory as well as on the suggestions arising from consultations with C. N. H. Long, W. Sperry and others.

PROJECT B-6-64-12-02

Sub-Project A.D.F.R.L. 22-4: Study of the Effects of Decreased Temperatures on the Metabolism of Various Phosphorous Compounds in Rats - Dr. H. F. Jensen, Chief Biochemist and R. B. [illegible], 1st Lt., DC.

This study is concerned with an analysis of the major tissues (muscle, liver and kidney) for their energy reservoirs and for the activity of such enzyme systems concerned with the energy supplying mechanisms.

Determination of adenosine triphosphate, which is regarded as the energy source directly coupled to function, in various tissues obtained from animals exposed to cold should indicate which of the tissues is most affected.

An investigation of the activity of enzymes of the cytochrome system, which plays an important role in the activation and transfer of oxygen, will be carried out simultaneously.

PROJECT B-6-64-12-02

Sub-Project M.D.F.R.L. 22-5: Study of the Effects of Hypoglycemia on the Control of Endocrine Secretion - Dr. H. F. Jensen, Chief Biochemist and G. L. Steeples, 1st Lt., MC.

p. 4,

A study will be made to determine the factors which control the secretion of various endocrine organs under stress (cold and shock).

In order to ascertain further evidence for the importance of the blood sugar level on the control of endocrine secretion the following experiments are contemplated: Effect of glucose administration on the function of the adrenal cortex and its cholesterol and ascorbic acid content and on the uptake of radioactive iodine by the thyroid.

PROJECT X-6-64-12-03

High Temperatures, Study of Physiological Effects of. Approved 24 Sept. 1942 in order to study the physiology of subjects in hot environment.

Sub-Project M.D.F.R.L. 02-1: Physiological Observations--Task Force Furnace - Dr. R. [illegible]. Clarke, Physiologist and P. J. Talso, Capt., MC.

Final report now in press.

PROJECT 5-3-4-12-05

Studies of Body Measurements as They Affect Physiological Efficiency. Approved 31 May 1946 in order to study body measurements in relation to functional dynamics.

Sub-Project M.D.F.R.L. 05-1: Photoplanimeter - L. W. Carpenter, Chief Engineer.

Final report now in press.

PROJECT B-6-64-12-05

Sub-Project M.D.F.R.L. 05-2: X-ray Stereopanoramograph - A. W. Carpenter, Chief Engineer.

Sub-Project M.D.F.R.L. 05-3: Cineroentgenography - A. W. Carpenter, Chief Engineer.

Various apparatus requisitioned to further these projects finally arrived in broken down or imperfect condition thus preventing use. Replacements have been ordered.

Difficulty in obtaining necessary construction materials has delayed construction of laboratory facilities for X-ray work.

PROJECT B-6-64-12-06

<u>Studies of Body Reactions and Requirements under Varied Environmental and Climatic Conditions</u>. Approved 31 May 1946 in order to study physiological reactions as altered by varied conditions.

Sub-Project M.D.F.R.L. 55-5: Effects of the Cold Pressor Test on Glomerular Filtration and Effective Renal Plasma Flow - F. J. Talso, Capt., MC, A. P. Crosley, Jr., Capt., MC and Dr. R. W. Clarke, Physiologist.

Report submitted 27 October 1947.

PROJECT 3-6-64-12-06

Sub-Project M.D.F.R.L. 06-1: Renal Circulation and Excretion as Affected by Stress - Dr. R. W. Clarke, Physiologist, A. P. Crosley, Jr., Capt., MC and P. J. Talso, Capt., MC.

Experiments on dogs are being carried out for the purpose of ascertaining the exact physiological mechanisms whose actions are responsible for the renal effects of peripheral cold.

PROJECT B-6-64-12-06

Sub-project [illegible]: Development of a Polarographic Flow Meter - Dr. E. A. Blair, Chief Physiologist.

Further investigation of the characteristics of the flow meter has been deferred pending delivery of apparatus.

PROJECT B-6-64-12-06

Sub-Project M.D.R.G.S. 06-1: Relation of Dietary, Metabolic and Mechanical Factors to Atherosclerotic Lesions in the Rat - Dr. D. E. Gregg, Chief Research Physician, H. Schachner, 1st Lt., MC and W. M. Harlich, 1st Lt., MC.

Methods for inducing hypertension adequate for this study continue to be investigated. In the different groups of rats fed thiouracil and thiouracil and cholesterol, blood cholesterol levels continue at two or three times the normal control values. There is no essential difference between the levels in the two groups.

PROJECT B-6-64-12-06

Sub-Project M.D.F.R.L. 06-7: A Possible Humoral Factor in Human Thermal Regulation - Dr. E. D. Palmes, Biochemist, H. Schachner, 1st Lt., MC, R. E. Albert, 1st Lt., MC and J. J. Hart, Cpl.

Jns 6,

Preliminary runs using one subject as donor and another as recipient gave suggestive evidence of the existence of a humoral factor which tended to increase the heat content of the resting subject. In the following runs a single subject was used both as donor and recipient. While it was realized that this procedure was less likely to prove the existence of the humoral factor it was made necessary by the unavailability of subjects for the two man runs. Avoidance of side reactions associated with transfusions was in favor of the single subject experiments also.

Three satisfactory runs were carried out, with two subjects receiving 100 cc. of whole blood, and one subject receiving 200 cc. No changes in thermoregulation were demonstrated.

The results of the one man experiment show only that the humoral factor was not demonstrated by this technique. We believe, however, that the two man approach still holds promise.

PROJECT R-6-64-12-06

Sub-Project [illegible]: Thermal Regulation During Fever - [illegible] Park, Capt., MC and Dr. E. D. Palmes, Biochemist.

The final report is now in press.

This project was presented as a paper at the Symposium on Military Physiology held at the Army Medical Center, 4-6 Dec. 1947.

PROJECT B-6-64-12-06

Sub-Project M.D.F.R.L. 06-4: The Aortic Factor in Hypertension - Dr. D. E. Gregg, Chief Research Physician and H. Schachner, 1st Lt., MC.

Sub-Project M.D.F.R.L. 06-5: Observations on the Accuracy of the Electromagnetic Flow Meter - Dr. D. E. Gregg , Chief Research Physician and H. Schachner, 1st Lt., MC.

Work on these two sub-projects still awaits machine shop work and the acquisition of appropriate apparatus.

PROJECT B-6-64-12-06

Sub-Project M.D.F.R.L. 64-6: The Effect of Certain Autonomic Drugs on Thermal Balance in Man - Dr. E. D. Palmes, Biochemist, H. Schachner, 1st Lt., MC, R. M. Albert, 1st Lt., MC and J. J. Hart, Cpl.

mi. 7,

It is generally known that the administration of certain autonomic drugs affects individual thermoregulatory mechanisms. Thus pilocarpine increases sweat secretion, atropine decreases it, and epinephrine raises metabolic rate. The object of this investigation is to elucidate the compensatory changes in thermoregulation brought forth by the administration of these drugs.

Several complete thermal balance studies have been made after subcutaneous injection of these drugs. The experiments have been carried out at two ambient temperatures (27 and 37 degrees centigrade) in order to ascertain the effect of environmental temperature on the compensatory mechanisms.

PROJECT B-6-64-12-06

Sub-Project M.D.F.R.L. 06-9: Analysis of Cortical Components Involved in Reflex Pupillary Dilatation to Clarify the Etiology of Anisocoria Resulting from Head Trauma - W. C. Wilson, Capt., MC.

ns. 6,

The stereotaxic apparatus developed has proved very efficient in locating cortical and subcortical centers and fiber tracts which mediate reflex pupillary dilatation through the oculomotor nerve, ciliary ganglion and short ciliary nerves. The anatomical identification of the involved structures was demonstrated by the Weil technique.

The centrifugal fibers of the excitatory gyri proeus and genualis were sectioned and the degenerated fibers could be traced by the Weil method to the caudate nucleus.

A combined electro-coagulating and stimulating apparatus has been developed which will permit activating the excitatory areas and subsequent blocking of their centrifugal connections at progressively descending levels. The anatomical identification of these coagulated areas will roughly indicate the course of the fiber tracts in question.

PROJECT B-6-64-12-06

Sub-Project M.D.F.R.L. 06-10: Development of a Photoelectric Polarimeter with Variable Electrical Field - E. L. Durrum, Capt., MC.

Further development work on this project awaits procurement and installation of Nicol prisms to replace polaroid discs and increasing of the sensitivity of the measuring bridge circuit.

PROJECT B-6-64-12-06

Sub-project M.D.F.R.L. 06-11: Biochemical Studies on Shock - E. L. Durrum, Capt., MC and Dr. H. Jensen, Chief Biochemist.

An increase in amino acids and a decrease in albumin in the blood has been observed in severe shock. Infusion of an albumin solution induces marked improvement in many instances.

A study of the mechanism of protein synthesis in the normal and shocked animal will include the following:

Determination of the respiratory quotient of various tissues from animals in shock.

Determination of the rate of deamination of liver tissue from shocked animals. Study of speeding up this reaction by the addition of certain substances to act as catalysts.

PROJECT B-6-64-12-06

Sub-Project M.D.F.R.L. 06-12: Spectrophotometric Studies of the Effect of Ultraviolet Radiation on the Skin - Dr. H. F. Kuppenheim, Chief Biophysicist and Dr. A. T. Krebs.

ws-10,

The use of the spectrophotometric method of recording light reflected from the skin aims at providing objective and quantitative studies of the erythema and the subsequent tan.

The first step will be the creation of a basis of reflectance curves of the normal skin of different colors, and from different body regions under standardized conditions.

In the next step erythemas under exact physical conditions (from natural and artificial light sources of known wave lengths and energy) will be created. The wave length region of and above 360 mμ which is known to produce a heavy and long-lasting tan, if a sufficiently high energy is irradiated, will be the main subject of study.

The erythemas and tans will be studied spectrophotometrically throughout their time course in combination with local temperature, biochemical, and physiological measurements.

Thus new and detailed knowledge of circulatory and pigment phenomena of the effect of other factors, as cold and wind, of the ultraviolet adaptation, of protective factors, etc. can be expected.

PROJECT B-6-64-12-07

Studies of Fatigue in Relation to Military Tasks. Approved 31 May 1946 in order to study the effects of stress and strain upon the body and the physiological factors that may be altered.

There were no sub-projects under B-6-64-12-07 this quarter.

PROJECT B-6-64-12-08

Studies of Physiological and Psychological Problems of Military Personnel in Relation to Equipment, Environment and Military Tasks. Approved 31 May 1946 in order to study the relationship of the soldier to his equipment, environment and task.

Sub-Project M.D.F.R.L. 08-1: Development of a Portable Apparatus for Study of Human Energy Metabolism - H. J. Spoor, Capt., MC and P. J. Talso, Capt., MC.

Final report on this sub-project awaits the results of sub-project 08-2.

PROJECT B-6-64-12-08

Sub-Project M.D.F.R.L. 08-2: Development of Electronic Oxygen Analyzer for Adaptation to Portable Metabolic Apparatus - H. J. Spoor, Capt., MC and J. H. St. John, Capt., MC.

ps. 11)

An oxygen analyzer utilizing a hot wire filament and combustion chamber has been incorporated within a small block of brass. Temperature and consequent resistant changes of the hot wire filament vary according to the percentage of oxygen in the test gas and these changes are recorded on a microammeter. By variation of the rate of flow of test gas, vaporization of fuel and temperature of the metal block, the device may be made extremely sensitive to small changes in oxygen content. However, the three variables must be made constant before standardization and final adaptation to portable work can be accomplished.

Following the perfection of the device, development of a single unit consisting of an infra-red type carbon dioxide analyzer and an electronic oxygen analyzer within a common metal block thermostatically controlled for use in all environments is anticipated.

Sally